Astronomy and Astro-Physics.

VOL. XII, No. 3. MARCH, 1893. WHOLE No. 113

General Astronomy.

THE PLANET JUPITER AND ITS SATELLITES.*

WILLIAM H. PICKERING.

Advantage was taken of the past favorable opposition to make a careful study of this planet, and of each of the well known members of its family. Owing to the small size of our telescope, it has been impossible to observe Mr. Barnard's recently discovered satellite, but the steadiness of our atmosphere has enabled us to study the other members of the system under very favorable circumstances.

JUPITER.

The first subject which absorbed our attention was an investigation of the nature and appearance of the spots and belts. Various magnifying powers were employed, but 450 diameters gave, on the whole, the best results. Under the most favorable visual conditions, it appeared that the surface of the planet consisted of a uniform white mass of cloud, and that over this stretched a thin, gauzy veil of a brown material, in structure not unlike our cirrus clouds. This covered the entire surface of the planet from pole to pole, but was more dense in some places than in others. Where it occurred in dense masses it formed the belts, where it was thin, we had the spaces between them. Occasionally a round or elliptical hole of 1″ to 2″ in diameter, penetrated this layer. If the hole occurred in a belt, it was very conspicuous, but if it occurred between the belts, it was much less so. These holes are the well known white spots upon Jupiter, and are, with one or two exceptions, the only regions that appear entirely clear of the gauzy veil above mentioned. As the white spots seemed to occur indifferently either in or between the belts, it was inferred that they had their origin in the uniform white layer of the planet, and penetrated the cirrus layer from below. There was one narrow white streak parallel to the belts, and not over 1″ in breadth, where the cirrus layer was so attenuated that we

* Communicated by the author.

could not be sure that it existed at all, but this region apparently differed from the other spaces only in degree and not in kind. The great red spot itself was extremely faint, and with difficulty distinguished. The space above it, however, excepting at its following end, was entirely clear of the cirrus formation, and thus indicated its whereabouts. The spot was, in fact, apparently seen through a hole in the cirrus as if it formed a portion of the white surface beneath. In short, it appears that were it not for this insignificant light gauzy veil of brown cloud, we should find the surface of Jupiter, like that of most of the other planets in the solar system, almost a perfect blank. This gauzy structure must float in a nearly transparent atmosphere surrounding and rising above it, and it is this atmosphere which causes the absorption, and which almost completely obscures the belts at the limb of the planet. A further reference to this atmosphere will be made later on, in describing the phenomena of the satellites.

THE SATELLITES.

We may classify the physical peculiarities of these bodies in the order of the facility with which they may be detected.

(*a*). *Relative Brightness*. The smallest telescope will show that the 3d satellite is the brightest of the four. The others follow in the order 1st, 2d and 4th. Under certain circumstances, as will appear later, the 2d may equal the 1st. Otherwise we have never detected any change in this order. Their mean magnitudes, as given in the Harvard Observatory Annals, Vol. XI, p. 276, are 5.2, 5.6, 5.8 and 6.4.

(*b*). *Size*. It requires a much more powerful telescope to clearly see the discs of the satellites. With such an instrument it is found that the 3d is the largest of them that the 4th is a little inferior to it, and that the two others are much smaller, and follow in the order, 1st, 2d. From this it follows that the 4th is very much darker colored than the other three.

(*c*). *Color*. These observations require a large telescope and a very clear atmosphere. Taking the color of Jupiter between the belts as our standard of white, the 1st and 2d satellites may be described as golden yellow. They are in general almost precisely the same color, but if there is any difference between them the 2d inclines more to green. The 3d is of a greenish yellow color quite different from the other two. On one occasion recently I saw the 2d half way in color between the 1st and 3d. The 4th is dark greenish grey and strikingly darker than the other three. As these are all non-actinic colors, this explains the fact that it requires from two to four times the exposure to secure a satisfac-

tory enlargement of the satellites, that it does to obtain an enlargement of Jupiter itself upon the same scale. Also, that while the 1st and 2d are intrinsically the brightest to the eye, that the 3d requires the shortest exposure photographically.

(*d*). *Phase.* We now come to an observation of which only the most favorably located telescopes are capable, that of watching the change of shape as the satellite enters the shadow of its primary. The difficulty of course increases in the inverse order of the size of the satellite.

(*e*). *Diffraction Spot.* This phenomenon was first noticed at this Observatory in August 1891, and was described in the *Astr. Nach.* 3079. It consists of a black spot visible upon the surface of the satellite, and apparently due to diffraction. If the lens is in perfect adjustment, it is central, otherwise it appears near the edge of the disc. If the seeing is very good the spot is very small but increases in size as the character of the definition diminishes. Its appearance undoubtedly depends more or less upon the size of the satellite and of the objective. We frequently see it upon the 3d satellite, occasionally upon the 4th, but rarely upon the 1st or 2d. Unless all of the above described phenomena can be clearly seen it is probably useless for the observer to attempt to detect those that follow. Neither should he make the attempt with a power much lower than 700 diameters. He should also adjust his objective, if necessary, so that it shall not give the least trace of a wing under the highest power, even when thrown slightly out of focus. Possibly the best way of introducing our results will be to give a brief history of the observations that led up to them.

Upon October 8th of the past year, I began a series of measurements with the 13-inch telescope of the diameters of Jupiter's satellites. Upon the next evening, I undertook to measure the 1st, when at the first glance I noticed to my surprise that its disc was not circular, but very elliptical. A brief computation the next morning showed that if my measurements were correct, that the polar flattening would correspond to a rotation period of about forty minutes, assuming a uniform density. Observations upon the next evening confirmed my first measurements. Some of the other satellites were also measured and I then returned to the first one, when to my astonishment, instead of showing an elliptical disc, it showed one that was perfectly circular, precisely like the other satellites. I could scarcely believe my eyes, but as I continued to watch and measure, I saw the disc gradually lengthen again and assume the elliptical form, and I then understood what had really been found. The 1st satellite has the form of a prolate spheroid or ellipsoid, or in popular par-

lance is "egg-shaped." The two minor axes are approximately equal, and the satellite revolves about one of them, or as we may say, it revolves "end over end." Within a few days, after this observation had been satisfactorily confirmed, it, with some facts pertaining to the other satellites, was cabled to the States, and published in the *New York Herald.*

Within a week from the date of my first observation, each of the other satellites had been recorded at some time as presenting an elliptical disc. But now a new difficulty arose,—in their cases the ellipticity was much less marked than in the case of the 1st satellite, and my assistant, Mr. Douglass, while readily confirming the ellipticity of the 1st, declared that the others always appeared to him to be circular. Nor was this all, the main difficulty lay in the fact that the three outer satellites when elliptical, appeared shortened equatorially, not lengthened, and this result was confirmed by the micrometer. In other words, these three satellites do not seem to revolve about their minor axes! Their rotation, therefore appears to contradict one of the most elementary principles of physics. It is chiefly for this reason that I have refrained from making any publication since my first telegram. I at first assumed that the result was due to an optical illusion, and tried various experiments, such as using the two eyes alternately, and turning the head through an angle of ninety degrees. The elongation nevertheless remained persistently in the same direction. I next thought the effect might be due to light and dark spots, suitably placed upon the surface. But when the satellites are in transit, and about disappearing, these spots should become visible. Nothing of the sort is seen, however, although surface markings have been discovered upon the 1st, 3d and 4th satellites. It was next suggested that the axes of the satellites might be greatly inclined to the plane of their orbits, and thus cause, not a shortening of the assumed equatorial, but an apparent lengthening of the assumed polar diameter, thus producing the same effect on the eye. The micrometer negatived this theory. Of late, probably owing to training of his eye, Mr. Douglass has been able to confirm my observations upon the three outer satellites, and we now both see them elliptical at the same times, and our position angles agree with one another within a few degrees. A possible explanation of their shape and revolution that has occurred to me is that of an irregular distribution of density in their interiors. This explanation seems improbable, and I therefore merely announce the facts that:

(*a*). The 1st satellite is a prolate ellipsoid revolving about one of its minor axes in a period of $13^h\ 03^m.0$.

(*b*). The discs of the 2d, 3d, and 4th satellites at regular intervals assume the form of ellipses, and this periodic change is presumably produced by a rotation upon their axes.

In dealing with further details the satellites may best be taken up separately:

First Satellite.—The period of rotation of this satellite, as above stated, is $13^h\ 03^m.0$, and this result has been abundantly confirmed by repeated prediction and verification of its ephemeris. It follows from its shape as above described that its disc appears perfectly circular once every six and a half hours. This appearance lasts for half an hour. The remainder of the time it appears more or less elliptical. When at a maximum the major axis exceeds the minor by about ten per cent. Under these circumstances it will be seen that the ellipticity is considerably greater than that of Jupiter. Its equator is inclined to the plane of its orbit a trifle over ten degrees, and the precession of its equinoxes occurs with extraordinary rapidity. A complete revolution probably takes place in about twenty-six days, but further observations are required to make this determination conclusive. The disc bears one or more nearly longitudinal narrow dark markings. The following ephemeris for the month of March, 1893, gives the approximate Greenwich Mean Time at which the satellite assumes the circular phase, and is therefore at minimum brightness:

FIRST SATELLITE.

d	h	m	d	h	m	d	h	m	d	h	m	d	h	m
1	02	03	7	08	07	13	14	11	19	20	16	26	02	21
1	08	34	7	14	39	13	20	43	20	02	47	26	08	52
1	15	05	7	21	10	14	03	15	20	09	19	26	15	24
1	21	37	8	03	41	14	09	46	20	15	51	26	21	56
2	04	09	8	10	13	14	16	17	20	22	22	27	04	27
2	10	40	8	16	45	14	22	49	21	04	53	27	10	58
2	17	11	8	23	16	15	05	21	21	11	25	27	17	30
2	23	43	9	05	47	15	11	52	21	17	57	28	00	02
3	06	15	9	12	19	15	18	23	22	00	28	28	06	33
3	12	46	9	18	51	16	00	55	22	06	59	28	13	04
3	19	17	10	01	22	16	07	27	22	13	31	28	19	36
4	01	49	10	07	53	16	13	58	22	20	03	29	02	08
4	08	21	10	14	25	16	20	29	23	02	34	29	08	39
4	14	52	10	20	57	17	03	01	23	09	05	29	15	10
4	21	23	11	03	28	17	09	33	23	15	37	29	21	42
5	03	55	11	09	59	17	16	04	23	22	09	30	04	14
5	10	27	11	16	31	17	22	35	24	04	40	30	10	45
5	16	58	11	23	03	18	05	07	24	11	11	30	17	16
5	23	29	12	05	34	18	11	39	24	17	43	30	23	48
6	06	01	12	12	05	18	18	10	25	00	15	31	06	20
6	12	33	12	18	37	19	00	41	25	06	46	31	12	51
6	19	04	13	01	09	19	07	13	25	13	18	31	19	22
7	01	35	13	07	40	19	13	45	25	19	50			

Second Satellite.—This satellite has given us more trouble than any of the others, and has proved to be a very difficult object to observe. At times it appears circular, and at times slightly elliptical. Sometimes the major-axis lies in the direction of the orbit, and at other times at right angles to it. This appearance has been further confirmed by micrometric measurements. The ellipticity is decidedly less than that of the 1st satellite. Its shape in short appears to be that of an ellipsoid of three unequal axes, revolving about the middle one. Its equator lies in the plane of its orbit. No surface markings have been detected upon it. Its period of rotation is $41^h\ 24^m$, or about an hour short of the time required to complete half a revolution in its orbit.

A curious observation was made in connection with this satellite upon the night of December 11. The satellite was about to be occulted, and was decidedly shortened equatorially at the time. Owing to the inclination of its orbit to the line of sight it did not pass behind the center of the planet, but somewhat above it, the position angle between the point of contact and the planet's equator being estimated at about thirty degrees. The satellite retained its shape until almost in contact with the limb, when the major axis of its ellipse suddenly changed its position angle through thirty degrees, becoming parallel to the limb of the planet. Now the interest of this observation lies in the fact that this is just the sort of change that we should expect would be produced if Jupiter were surrounded by a comparatively rare atmosphere, extending several hundreds of miles above its surface, such as presumably extends several thousand miles above the suface of the Sun and thirty or forty miles above that of the Earth. The observation is a very difficult one, however, and whether the change of shape was real or only apparent must be settled by subsequent research.

The following ephemeris for the month of March, 1893, gives the approximate Greenwich mean time at which this satellite presents the smaller of its two elliptical phases, that is, the one in which the minor axis is parallel to the plane of its orbit. Under these circumstances it shines with its minimum brilliancy.

SECOND SATELLITE.

d	h	d	h	d	h	d	h
1	15.2	9	09.5	17	03.8	24	22.1
2	11.9	10	06.2	18	00.5	25	18.8
3	08.6	11	02.9	18	21.2	26	15.5
4	05.3	11	23.6	19	17.9	27	12.2
5	02.0	12	20.3	20	14.6	28	08.9
5	22.7	13	17.0	21	11.3	29	05.6
6	19.4	14	13.7	22	08.0	30	02.3
7	16.1	15	10.4	23	04.7	30	23.0
8	12.8	16	07.1	24	01.4	31	19.7

Third Satellite.—On account of its size and brightness this is much the easiest satellite to observe. Indeed even the occasionally elliptical shape of its disc has been noted by Lassell, Secchi, and Burton. None of these observers, however, seem to have been able to repeat their observations with sufficient frequency or precision to construct an ephemeris from them, or determine the inclination of the axis. When the disc is most elliptical the major axis exceeds the minor by about $0''.2$, a very appreciable quantity. The satellite appears to be of the shape of an oblate spheroid (like a watch), revolving about one of its major axes. Its equator is inclined about eighteen degrees to the plane of its orbit, and it presents the elliptical phase twice in each revolution about its primary. Like our Moon, therefore, its period of rotation coincides, at least approximately, with that of its revolution in its orbit. The time at which it reaches its maximum ellipticity occurs thirty-four hours after inferior and superior conjunction. Its surface markings are readily seen, especially during transit, the most conspicuous being a dark belt situated in the northern hemisphere, and inclined about fifteen degrees to its orbit. The position angle of the belt was determined upon a different date from that of the direction of the minor axis of the ellipse, and it is quite possible that the two are really parallel. There is some evidence also, from the shape of the belt that the south pole of the satellite is inclined towards us ten or more degrees, which would materially increase the inclination of its equator to its orbit. There are also indications of a rapid precession, since the position angle of its major axis appears to vary. Various dark lines and shadings spread southward from the belt, some of them uniting in part, at least, to form a southern belt parallel to the northern one, but less strongly marked. At times the southern pole has appeared somewhat brighter than the rest of the surface, but never brilliant as in the case of Mars. Like our

Moon and Mars the limb is rather brighter than the center of the disc. The following ephemeris, constructed like the preceding ones, indicates the time at which the satellite presents the maximum elliptical phase, and when it is consequently at minimum brilliancy during the month of March, 1893:

THIRD SATELLITE.

d	h	d	h	d	h	d	h
2	06						
5	20	13	00	20	05	27	09
9	10	16	14	23	19	30	23

Fourth Satellite.—This satellite usually presents a circular disc, but at conjunction with Jupiter it is elliptical, the major axis lying nearly perpendicular to its orbit. Its periods of rotation and orbital revolution are therefore identical. Its color is so dark that its surface markings are only seen with the greatest difficulty. They seem to consist chiefly of a broad, dark equatorial belt, the poles being slightly lighter and more greenish in color. The north pole has been seen much brighter than the south, but is not always so. Occasionally it has been thought that very minute dark and light spots have been detected upon its disc, the latter near the north pole. Webb states that he frequently has seen the 4th satellite surpass the 3d in brightness. Such an observation would certainly be of the greatest interest at the present time, and could only be accounted for either by the third becoming still darker in color than the fourth is at present, or by extensive white spots appearing upon the fourth, which latter hypothesis seems the more probable of the two. This satellite will exhibit a slight minimum of brilliancy upon the nights of March 8, 17, and 25.

At times the discs of the satellites have seemed to be of a slightly irregular shape. That is to say, one side of the so-called ellipse has seemed flatter than the other. This has been particularly noticed by Mr. Douglas, though I have occasionally seen it also. I am not inclined to consider it a genuine phenomenon, but rather due to some local cause, such as the action of the wind, combined with slightly inferior definition. No striking instances of change in intrinsic brilliancy from night to night have been noticed in our observations of the satellites, their colors and light not seeming to us more variable in general than that of the other members of the solar system. As far, therefore, as our observa-

tions go, I should be inclined to attribute most of the varying phenomena of light and dark transits to variations in the light reflected to us by the clouds on Jupiter, rather than to variations in the brightness of the satellites themselves.

Our micrometric measurements of the diameters have not as yet been completely reduced, but I may say that they confirm those of Engelmann, diminishing the size of each satellite possibly about two hundred miles. This, while increasing their densities slightly, still leaves them at an extraordinarily low figure. Taking the specific gravity of water as our standard, the density of the 1st satellite is less than 1.5, and the density of the 2d, less than 2.5. The densities of the 3rd and 4th satellites lie between these figures. As our telescopic definition is perfect, I do not see how it is possible for these results to be in error. That being admitted, the question arises of what can these bodies be composed? As shown in my paper published in ASTRONOMY for November, 1892, they are too small and too light to retain an atmosphere, excepting at a very low temperature, a temperature, in fact, which could not be very far above that of absolute zero. A low temperature is perhaps not improbable, but of what must the clouds be composed that form their visible surface? If the clouds are formed of liquid drops or bubbles, this liquid can certainly not be water. Besides, these clouds are not white when compared with those upon Jupiter. Shall we conclude that these are clouds of condensed oxygen, nitrogen, or hydrogen? If this hypothesis, taking into consideration the blackness of the 4th satellite, seems improbable, and we dismiss the atmospheric theory altogether, the only solids which are light enough for our purpose, exclusive of the alkaline elements, are those that are porous or hollow. There is still one course left open to us, however. It is that each of these satellites is nothing more than a very condensed swarm of meteorites, like Saturn's ring. The apparent revolution of the 3d satellite about its major axis, which is certainly not a difficult observation to repeat, indicates pretty clearly that there is something peculiar about these bodies, and it is possible that their real constitution may yet admit of mathematical demonstration.

Although it is quite probable that the number of astronomers who will have the optical means to confirm all of these observations is rather limited, yet there is one test that is within the reach of nearly everyone. This depends upon the fact that when the 1st satellite presents a circular disc, and the 2d is elongated equatorially, that there is very little difference between them in

brightness, and that, on the other hand, when the reverse conditions prevail, the difference between them is quite marked. The following ephemeris for March has therefore been prepared, Greenwich mean time being employed as before. Upon those dates marked with an * the 1st and 2d satellites will be found to be of approximately equal brightness. Upon those dates marked with a † the 1st satellite will conspicuously excel the 2d in brilliancy.

FIRST AND SECOND SATELLITES.

d	h	d	h	d	h	d	h
2	23.5*	9	09.2†	18	01.5†	24	01.4†
3	09.2†	9	19.2*	18	11.3*	24	11.4*
3	19.2*	12	20.7†	18	21.3†	24	21.3†
4	05.2†	13	07.3*	19	07.4*	28	09.5†
4	15.1*	13	17.3†	19	17.3†	28	19.5*
8	03.4*	14	03.3*	20	03.1*	29	05.5†
8	13.2†	14	13.2†	23	05.4†	29	15.4*
8	23.2*	14	23.6*	23	15.4*	30	01.4†

It is suggested that early observations of the relative brightness of these two bodies may be employed to determine their periods of rotation with considerable accuracy.

AREQUIPA, Peru, Jan. 2, 1893.

SWIFT'S COMET (a 1892).*

A. E DOUGLASS.†

This comet was first observed here on March 29*d* 21^h, G. M. T. For more than a month the photographic telescopes were turned upon it whenever possible and a large number of photographs were secured. It is owing to the amount of detail shown by these photographs and the evident results to be obtained by their thorough examination that this discussion of the work here has been so long delayed.

The most interesting series of plates were the fifty-six taken in the Bache 8-inch photographic doublet, on a scale of 20 millimeters to the degree. Of these, sixteen chart plates taken on twelve different nights from March 30th to April 27th are of the first quality. In them the definition is good and accurate comparisons can be made between different plates. Seven somewhat in-

* Communicated by Edward C. Pickering, Director of the Harvard College Observatory.

† First assistant at the Boyden Station, Arequipa, Peru.

ferior plates taken upon five additional nights are sufficiently good for many purposes. Twenty other chart plates were taken which, from various causes, were unsatisfactory. The list is completed by thirteen spectrum plates of which five show five or more bright lines in the nucleus and two show spectra of the tail at about 1° from the head.

The next series in order of interest was taken in the 2.5-inch photographic doublet, on a scale of 3.8 millimeters to the degree. Twenty plates in all were taken, of which twelve are satisfactory and have been used for purposes of measurement.

In addition a number of plates were obtained in the 13-inch refractor and in the 20-inch reflector which in extended study of the comet would be of great use.

A short examination of the Bache plates gave at once two empirical facts: 1st, the tail of Swift's comet was composed of luminous masses receding from the head at a measurable rate, and 2nd, the form of the tail depended largely on some varying force acting at the head.

We will proceed to investigate the first.

For purposes of measuring the velocity of recession from the head, eight points were identified, each point being found upon two plates, and their distances from the nucleus were determined. They may be subject to small errors owing to the hazy outlines of the comet itself. Nevertheless, one case is subject to no uncertainty. It occurs in the plates of April 7th and 8th when a slender curved stem connects the head with a conspicuous and well defined luminous mass at the base of the main tail (c_1 in Fig. 1 below). The results of these measurements are given in Fig. 1 in which the abscissas give the distance from the head and the ordinates show the mean daily motion of recession. The whole is expressed in minutes of arc.

Table I below contains the value of p (in the formula $y^2 = 4px$) for each point, and a weight assigned to it depending on its accuracy of identification. The mean thus found serves as the basis for the parabola* drawn in Fig. 1.

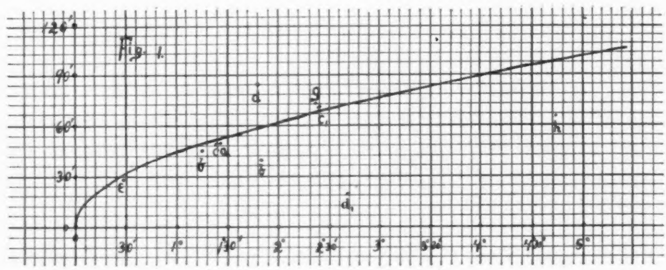
* The question of an ellipse in place of this parabola will, it is hoped, be discussed at some future time. For the present, the parabola is sufficiently accurate.

TABLE I. VALUES OF *p*.

Point.	*p* ′	Weight.	Point.	*p* ′	Weight.
a	7.2	1	*c*	6.9	1
b	3.6	1	c_1	9.0	6
d	16.2	1	*f*	6.6	1
d_1	0.6	0	*g*	9.3	1
e	7.2	1	*h*	3.3	1

Mean value of *p*, 8′.2

d_1 is omitted as being probably erroneous.



Adopting the simple formulas for constantly accelerated motion and an approximate distance from the earth of 100,000,000 miles, the acceleration in miles per day becomes 477,000. Per second it amounts to 0.33 feet.

The second topic—that the form of the tail depended largely on some varying force acting at the head—may be discussed in two parts: 1st, the general characteristics of the tail, and 2nd, the special phenomena within half a degree of the head.

In general, the tail may be described as a bundle of slightly divergent straight streamers, branching from each other and joined to the head by one, two, or three well-marked lines. Measurement of the tail consisted in determining its position angle at different distances from the head. For this purpose, both Bache and 2.5-inch doublet plates were used. The distances employed were 0°.7, 3°.2, 5°.0, 6°.3, and 12°.5. As the maximum difference between the mean position angles at these points was 2°.8, the tail may be described as nearly straight.

Special phenomena near the head exhibit so great diversity of detail that a general description is difficult. Many of the photographs show two brilliant lines leaving the head. The tail may be joined to one, both or neither of these. In the latter case it terminates in one or two slender central lines. The rest of the

photographs show a number of faint streamers leaving the head, with the tail sometimes but not always joining one of them. At least two plates show also a very curious twisted appearance of the southern branch of the tail.

Measurements of this part of the comet were first made of the position angle of the best marked line of connection between the head and the outer tail, and second of the position angle of the large jets of luminous matter forming independent tails. Estimates were also made of the duration of the twisting effect on the south side of the tail.

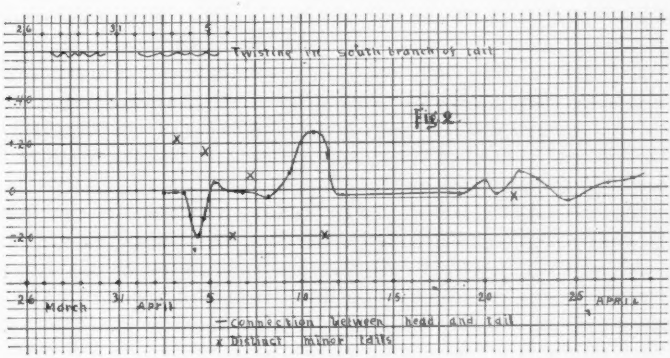


Fig. 2 gives the natural tangents of these position-angles for the date in which they left the head, as obtained by computation. The mean position angle of the whole tail for the date is used as the reference line at 0°.

In the upper part of the figure is given the approximate time in which the twisting effect originated in the nucleus.

The curve as it stands is quite irregular and suggests non-periodic outbursts from the head of the comet, or variations in the repulsive force of the Sun. It will be noticed that where the tail swings to one side there are large jets in the opposite direction, as if the whole resulted from some increase in activity in the head. It is possible that this activity in the comet is connected with solar disturbances in the same way that magnetic storms on the Earth are connected with certain classes of Sun-spots. An examination for such relationship might prove of the greatest interest. If found it would be strong evidence in favor of electricity as the basis of solar repulsion.

OBSERVATION OF THE PARALLAX OF O. ARG. 14320.*

F. P. LEAVENWORTH.

This star has been observed at the Cape of Good Hope; and Prof. Holden has begun a series of photographs for the purpose of determining its parallax. But so far as I know its parallax has not yet been published. It is a star of great promise to the parallax hunter. For its proper motion is 3″.7, and it has a companion star five minutes south of it, affected with exactly the same proper motion. These stars, to be sure, are only of the ninth magnitude, but proper motion rather than brightness is considered the best indication of large parallax.

My observations were made for the purpose of determining whether the star's parallax was large, rather than to determine accurately the amount of parallax. Only thirteen measures were obtained, and not all of these were made at a favorable time. On account of the southern declination of the star the observations were continued over a period of only four months. The measures were made during 1892 with the ten-inch equatorial of the Haverford College Observatory. They consisted of measures of the position angle and distance, and of the difference of right ascension and declination of a neighboring *fixed* star. The parallactic coefficient in declination was so small that the measures of difference of declination could not be used. The resulting parallax from the remaining measures is as follows:

For $\Delta\alpha$,	$+0''.02 \pm 0''.04$
For position angle,	$-0\ .11 \pm 0\ .07$
For distance,	$-0\ .23 \pm 0\ .04$

It is probable that this discrepancy is due to personal equation, as the measures in each set agree well among themselves. Such results are not uncommon in micrometrical work when large distances are measured, and undoubtedly show that the micrometrical method should yield to the photographic.

There is a twelfth magnitude star situated in the direction of the motion of this star, which in the course of about twenty five years will form a double star with it. A single night's observation gave its position

1892.43 $\quad$ 188°.7 $\quad$ 93″.76

UNIVERSITY OF MINNESOTA.

* Communicated by the author.

THE BALANCE ROOF FOR TELESCOPE BUILDINGS.*

A. E. DOUGLASS.

A simple form of roof for sheds of limited size has been adopted by us and found to work satisfactorily. A description of it may prove of some interest.

The telescope room is ten feet square, and supplied with the ordinary gable roof. The roof, however, separates into north and south halves which, on specially devised hinges at the lower corners, may be turned completely over and rest in a horizontal position on supports outside. The gable ends also are supplied with hinges, and can be turned inwards to hang down entirely out of sight.

Each half of the roof has a frame of light wood on which is stretched canvas heavily painted. The hinges are half-inch iron pins supported by strong braces at each corner. They are placed several inches from the walls so that nothing may interfere with the free movement of the roof. At the same point a flat iron bar projects from the roof itself some 20 inches beyond the hinge and carries on its end a counterpoise weight of 25 pounds. The weights, though not essential, are nevertheless a most important feature, as they prevent the severe strain a roof of such size would suffer when lifted by one end only. Moreover they enable one to open the roof almost instantaneously, and almost without muscular labor.

Pulleys, ropes, wheels and great weight being avoided there is less chance of its getting out of order, yet it must be provided with fastenings to prevent the wind blowing it to and fro.

The roof is inexpensive and easily made, and can be recommended for use in eclipse expeditions. Owners of small telescopes also might find it well adapted to their requirements.

SOME EFFECTS OF A COLLISION BETWEEN TWO ASTEROIDS.*

SEVERINUS J. CORRIGAN.

Although, for reasons set forth in my communication to No. 112 of ASTRONOMY AND ASTRO-PHYSICS, the minor planets between which has probably occurred a collision that has resulted in the formation of Holmes' comet (or pseudo comet) have not

* Communicated by the author.

been discovered, and known as members of the asteroid system, I think that certain of the observed phenomena of this remarkable body are, when properly interpreted by means of well known principles of "celestial mechanics," sufficient to give us much valuable information in regard to the several magnitudes of the hypothetical bodies in collision, and to furnish collateral testimony of considerable weight, as to the truth of the hypothesis which was enunciated in No. 111 of ASTRONOMY AND ASTRO-PHYSICS in regard to the origin of Holmes' comet.

One very probable effect of a collision between two such bodies moving with a considerable relative linear velocity, (or of the *explosion* of a single asteroid), would be a complete, or a partial, rupture of one or of both of the moving masses and a dispersion of the resulting particles, in all directions. Considering, first, the particles impelled in a vertical direction, or radially from the center of gravity of the asteroid, it is obvious that if there were no other matter in existence in the surrounding space, the particles thus projected would, after reaching any height, h, due to any initial velocity, u (provided the latter did not exceed an amount definitely depending upon the mass and the radius of the body from which the particles had been ejected), fall back toward the center of gravity of the asteroid, and to the points whence they had been projected. But the existence of any considerable mass of matter in comparatively close proximity to the body whence these particles had arisen would cause a very important change in the motions of such particles. Thus in the case of particles impelled radially from an asteroid, the great mass of the Sun would exert such an influence upon the aforesaid particles, that when the height, h, due to any initial velocity, or impulse, u, attain a value, ρ (dependent upon the mass, m', of the asteroid, relative to that of the Sun, and upon the radius-vector, r, of said asteroid), the ejected matter would not fall back toward the center of gravity of the body from which it had arisen, but would pass under the control of the Sun, move in orbits around that body, and be gradually dispersed in space under its influence. At the height, ρ, the disturbing action of the Sun upon the ejected particles, must equal the direct action of the central body, or asteroid, thereon. Now this disturbing action of the Sun is the difference between the direct action of the solar mass, upon the asteroid, and upon the particles aforesaid. The direct action of the Sun upon the central body is expressed by, $\frac{k^2}{r^2}$, the denominator being the well known constant of

acceleration due to the solar mass. The direct action of the Sun upon a particle at distance ρ and exerted along the radius-vector, r, will be $\frac{k^2}{(r+\rho)^2}$, to a sufficient degree of approximation for small values of ρ; the maximum disturbing force of the Sun, upon such particle, must, therefore, be,

$$\frac{k^2}{r^2} - \frac{k^2}{(r+\rho)^2}, \text{ or } \frac{k^2\rho}{r^2} \cdot \frac{2r+\rho}{(r+\rho)^2} \qquad (A)$$

The direct action of the central body or asteroid, upon the same particle will be,

$$\frac{m'k^2}{\rho^2} \qquad (B)$$

m' being the mass of the asteroid relative to that of the Sun, which is taken as unity.

Now since at the limit ρ, at which the particles pass from the control of the asteroid into that of the Sun, and begin to disperse in space, under the disturbing action of the latter body, the direct action of the asteroid upon the particles, or the expression (B), must be equal to the disturbing action of the Sun upon the same particles, or to the expression (A), we have,

$$\frac{m'k^2}{\rho^2} = \frac{k^2\rho}{r^2} \cdot \frac{2r+\rho}{(r+\rho)^2} \qquad (1)$$

Reducing this equation we will have, to find the mass of the central body, or asteroid in terms of the solar mass,

$$m' = \frac{\rho^3}{r^2} \cdot \frac{2r+\rho}{(r+\rho)^2} \qquad (2)$$

Therefore, all the quantities that are necessary to be known for the determination of the mass of the central body (*i. e.* of the combination of two asteroids in the case of a collision, or of one asteroid if the comet has been caused by the explosion thereof), are the values of r and that of ρ. Now, I purpose to show that from the value of m', as found through equation (2), the diameter of the central body can be found, in terms of that of the Earth, and hence in miles. Knowing m', through equation (2), we can find M, or the mass of the body, in terms of that of the Earth, from this equation,

$$M = \frac{m'}{E} \qquad (3)$$

In which E represents the mass of the Earth relative to that of the Sun, its approximate value being $\frac{1}{326800}$. The relation be-

tween volume, mass, and density is expressed by the well known equation,

$$V = \frac{M}{D} \qquad (4)$$

It follows, therefore, that if the density of the central body, relative to that of the Earth, be known, V can be found from equation (4). The relative diameter will then be $V^{\frac{1}{3}}$, and this quantity multiplied by 7913, or the mean diameter of the Earth in miles, will give the diameter of the central body in the same measure. In the practical application of the principles above set forth, to cases such as that of Holmes' comet, the first step is to find ρ, or the radius of the "sphere of control." The following considerations furnish a clue which, I think, leads to a knowledge of this quantity. The greater portion of the ejected particles, lying within the "sphere of control," a condensation or concentration of luminous matter must appear surrounding the central body, or nucleus. The diameter of this condensation will be 2ρ, and if the angular diameter thereof, represented by a, be determined instrumentally when at a maximum, and the geocentric distance, Δ, of the body at the same time, be known, the value of ρ can be found through the equation,

$$\rho = \Delta \tan \tfrac{1}{2} a \qquad (5)$$

The valuable observations made by Dr. H. C. Wilson of "Goodsell Observatory," and published in No. 111 of A. AND A. P., indicate that this condensation attained maximum dimensions on, or near Dec. 10, 1892, when it was about 1′ in diameter, and this furnishes the value of a.

The value of Δ at the same time was, as I have determined from Schulhof's elements (A. AND A. P., No. 112), 1.85032, and that of the radius-vector r, was, according to the same authority, 2.50828. Therefore the value of ρ found through equation (5) was .000269117, in terms of the Earth's mean distance from the Sun, which is taken as unity. The radius of the "sphere of control" was, therefore, about 25,000 miles.

With this value of ρ and with that of r, as given above, the value of the mass is found through equation (2), to be $\frac{1}{4048950000000}$ that of the Sun's mass, and through equation (3), $\frac{1}{1238970}$ that of the Earth. The latter value is that of M, which, through equation (4) gives the volume of the body in terms of that of the Earth, when the density of the former in terms of that of our globe is known. Did space permit it could be shown that

the density of the body is probably not very different from that of the Earth, which is taken as unity. Making therefore D unity in equation (4), the volume of the body becomes equal to the mass M above given.

The relative diameter will therefore be $M^{\frac{1}{3}}$, or $\frac{1}{107.4}$, which multiplied by the number of miles in the Earth's mean diameter, (*i. e.* by 7913), gives 74 miles as the diameter of the central body, or asteroid. If this central body be considered as composed of two asteroids of equal sizes, which have combined through a collision, the diameter of each asteroid would be 59 miles. It is known that the diameters of asteroids, in general, are so small that they cannot be well determined by direct measurement, but, from the observed brightness of divers members of the system, it has been approximately determined that the smallest ones are from 20 to 40 miles in diameter, and the largest from 200 to 400 miles. In this connection I would call attention to the fact that the diameters of the hypothetical bodies as determined by the process above set forth, lie close to the former limits, and since, as I have shown, the asteroids concerned in the formation of Holmes' comet must have been unknown and therefore probably small members of the system, this fact is very significant I think.

If we take the mean opposition magnitude of Vesta, the largest member of the system, as 6.0, and its diameter as 400 miles, we can determine the mean opposition magnitude of the body above referred to, and whose diameter is 74 miles, through the following equation,

$$\mu = 6.0 + 2.5 \log \left(\frac{a \,.\, \Delta}{a' .\, \Delta'}\right)^2 + 2.5 \left(\frac{S}{S'}\right)^2 \qquad (6)$$

in which a is the mean distance, Δ the mean opposition geocentric distance, and S the surface of the body aforesaid, and a', Δ' and S' the corresponding quantities appertaining to Vesta. The result is 12.0, which is not far from a mean of the same magnitudes for the whole asteroid system. By using r and Δ as found above for Dec. 10.5, 1892, the theoretical magnitude at that time was about 10.5.

On Nov. 22, 1892, Dr. H. C. Wilson noted the magnitude of the nucleus of the comet as 10.0, while on Dec. 10, 1892, it appeared to him as a star of the 12th magnitude surrounded by a concentration of luminous matter, about 1′ in diameter. Considering that according to the "collision" hypothesis, this matter had been deducted from the nucleus, thus reducing its surface, and

therefore its brightness, the relations between the results of observation, and the deductions from the principles above set forth, are very significant, and furnish strong support to the above named hypothesis.

ST. PAUL, Feb. 10th, 1893.

A SIMPLE METHOD OF REDUCING TIME OBSERVATIONS MADE WITH THE TRANSIT INSTRUMENT.*

CHARLES B. HILL.

For Amateur Astronomers.

In these days of accurate time-signals from some neighboring Observatory the amateur astronomer falls into the habit of neglecting his transit instrument, and depending entirely upon the noon signal for his clock error and rate. No matter what care is taken to secure accuracy, I venture to say that a clock rate, carried from the noon signal to the epoch of the midnight observations in connection with which it is used, will frequently be in error more than half a second. The day and night rates of the average chronometer have, usually, very different values.

For certain Observatory work the amateur should observe the nicest accuracy in regard to his local time, which is best obtained (as is well known) by means of a transit instrument. Even a very small transit, approximately adjusted to the meridian, and used with ordinary care, will afford the means of determining the local time with the greatest precision. Only the larger transits, to be found in the more pretentious observatories, may be depended upon to give an accurate chronometer correction by the observation of one or two "time-stars." Smaller sized instruments, such as I am supposing the amateur to use in his work, will twist and squirm under every change of temperature, and in accordance with every imaginable variety of "strain," invisible of course to the observer. For this reason anyone can not obtain an accurate clock correction by the means usually suggested to the amateur: that is, by adjusting the azimuth according to some mark, and levelling the axis with the spirit-level, *and performing these adjustments immediately before observing the selected stars.* It takes some time for any good instrument to settle into comparative stability, and the only way to obtain accurate results with the transit is to make the adjustments as

* Communicated by the author.

nearly as may be, once for all, and then to leave the instrument entirely alone. Many of the transits sold to amateur workers would be much more useful as instruments of precision, if they had no moving parts for effecting the azimuth and level adjustments.

The proper way to do is to "reduce" each set of observations made with the transit instrument, and to determine from the observations themselves the instrumental constants and the chronometer correction. Without here going into the elementary theory of the transit instrument, let me suggest to the amateur that he review the subject in some standard astronomy, for example, in Professor Young's *General Astronomy*, pages 36-42.

It will then be clear to him that the adjustments of the transit instrument, no matter how carefully made, will never be perfect, but that there will be three principal sources of error, viz.:

(1.) The error of *level*. If the transit axis is not truly horizontal, the arc described in the heavens by the optical axis of the instrument will not coincide with the meridian, but will be a great circle deviating from the meridian most in the zenith, and intercepting it at the north and south points of the horizon.

(2.) The error of *azimuth*, which causes the telescope to revolve in a plane which intersects the true meridian in the zenith.

(3.) The error of *collimation*, on account of which the middle thread does not exactly coincide with the optical axis.

A rigorous discussion of observations made with the transit instrument becomes then a somewhat difficult problem which is fully treated in the different works on spherical and practical astronomy [*vide* W. Chauvenet, Manual of Sph. and Pr. Astr., Vol. II; or W. W. Campbell, Handbook of Pr. Astr., etc.]. I believe that there are many amateur astronomers in the United States who are thoroughly reliable observers, and are capable of doing useful work, but who nevertheless have never had an opportunity for acquiring that knowledge of mathematics necessary to apply the methods given in a text-book of practical astronomy for the reduction of a set of transit observations. Still it is possible with the aid of a few extremely simple algebraic formulæ to obtain from a "set" of stars observed with a portable transit results which will be almost identical with those obtained by a thorough discussion of the same observations according to the most refined methods.

It is proposed in the present paper to describe such a method for the benefit of my fellow amateurs, some of whom may find it useful, as I have. It was learned while in Professor Davidson's

office, in the Western Branch of the U. S. Coast and Geodetic Survey, and is derived from different printed and manuscript papers of Charles A. Schott, Esq., Assistant in Charge of the Computing Division.

In order to make the present paper in a measure complete, I append herewith certain easy rules for the

PRELIMINARY ADJUSTMENTS.

It is advisable to reduce the instrumental errors as nearly as possible to zero. This should be done when the transit is first set up; after which the adjustments should be rarely disturbed. The small residual errors will then be reduced from the observations. They are called the "instrumental constants," and are denoted as follows:

a = azimuth error, or constant.
b = level error, or constant.
c = collimation error or constant.

To adjust the level. Place the striding level on the axis and read one end—say the *west* end. Reverse the level and read the *west* end again, being careful not to change the length of the bubble in reversing. Set the *west* end to the mean of these two readings by changing the adjusting screws on the *level.*

To level the instrument. Having performed the preceding operation, bring the bubble *central* by changing the adjustment of the leveling screws on the transit.

Collimation. If this adjustment can be made in the day-time, point the telescope on a distant mark either north or south, and at least a mile away, for good definition. (It is unnecessary to say that the sidereal focus of the instrument must be first determined, and then left unchanged). Pick out some feature of the mark which is exactly bisected by the middle thread. Then reverse the telescope in the Ys and see if the same point is still bisected by the thread; if it is, the collimation is good, if not, move the thread *half-way towards the object* by changing the screws carrying the reticle plate.

Two or three trials of this sort will effect a close adjustment for collimation.

If made in the night, some very close polar star must be substituted for the fixed mark, and the telescope quickly reversed in the Ys. Polaris is, of course, the most suitable star for this operation, with very small instruments, and this star may be observed at any time by shifting the instrument in azimuth. When near

E. or W. elongation, Polaris is the best possible object for this purpose.

Azimuth. The two preceding adjustments can be effected mechanically, but placing the instrument in the true meridian can, originally, be only done by means of the stars themselves. First, find the approximate error of the time-piece by the transit of some star close to the zenith. Then find at what time, by the clock, some close polar star will come to the meridian. At the proper time place the middle wire on the star (by moving the transit "in azimuth")—it will then be approximately in the meridian.

It may be found that the level of the instrument has been changed in this latter operation. If so, that should be again adjusted.

When the azimuth of the transit has been well established, a suitable mark can probably be found (in either direction, north or south) by means of which the adjustment may be effected in future, should it become necessary.

[*Inequality of Pivots.* It may be that the two pivots of the transit axis are not of the same diameter. With the modern instruments this error is hardly appreciable, and may usually be neglected if indeed a value of the constant is not given by the instrument maker. Formulæ for determining the inequality will be found in Assistant Schott's paper on the "Determination of Time, Latitude, Longitude and Azimuth," published by the U. S. Coast and Geodetic Survey, etc.].

In what follows we will consider the simplest way of deducing from all the observations made, the best value for the instrumental constants, and the chronometer correction.

TO REDUCE THE OBSERVATIONS.

Let us suppose a "time set" has been observed in the following manner:—

(1). A certain number of *quickly moving stars*, at least two or three, (say one near the equator, one a little south of the zenith, and one a little north of the zenith), and also *one slowly moving star*, about 15° or 20° from the pole. The striding level should be read at least twice.

(2). Then, the telescope having been reversed in the Ys a similar selection of "time stars," and one "azimuth star." Level readings, as before reversal.

The time of transit over each thread should be recorded in the note book: it is convenient to have this ruled in vertical columns, three or four to the page, as in the form following:

DATE.—APRIL 1, 1884.

Star	α Urs. Maj.			
Clamp. (or illumination)	E.			
Factors A B C	− 0.90 1.96 2.16			
Level D Readings R	E. W. 43 0 51.0 59.5 34.5			
Threads 1 2 3 4 5 6 7	36.1 08.9 41.0 13.5 46.2 18.9 10 57 51.4			
Mean Thread	10 56 13.71			
Corrections: Rate Level Collimation Azimuth				
Corrected mean Tabular R. A.	10 56 36.50			

ΔT

The level readings should be taken in the following manner: Place the level on the axis, and record the reading of the east end, and of the west end. Turn the level 180° (*i. e.* reverse it), place it in the axis again, and record the east and west ends under similar readings of level "direct."

In the preceeding form will be noticed a space for *clamp or illumination*. Some feature of the telescope is taken as a mark to denote the position of the instrument; either the side to which the clamp or the circle is attached, or through which the illumination is allowed to pass, is considered the marked end so that if we have "clamp W" in the first half of the observations, (for example), it will be "clamp E" when the telescope is reversed.

The instrumental errors of azimuth, level and collimation (represented by a, b and c respectively) should be reasonably small, and the value of the level division in seconds of time must be known. The "inequality of pivots" produces no appreciable effect upon the final result when the transit is reversed but allowance for this error will probably produce more harmonious results. When any threads are missed it is convenient to know the equatorial intervals between the threads. This will be illustrated in the annexed "example."

The factors A, B and C represent the effect upon the time of transit of each star for an error of *unity* in azimuth, level and collimation respectively. They depend for their value upon the latitude of the station, and the declination of the star:

$$A = \sin(\varphi - \delta) \sec \delta$$
$$B = \cos(\varphi - \delta) \sec \delta$$
$$C = \sec \delta$$

Where

$\delta =$ the declination of the star, and
$\varphi =$ the latitude of the place.

The amateur observer should form a table of these factors for all the principal clock stars, computed for the latitude of his Observatory. He may, without much trouble, compute the factors for declination $= -20°, -10°, 0°, +10°, +20° +30°, +35°, +40°, +45°, +50°, +55°$, (and then for each "azimuth star" which he may employ); from the values thus obtained the factors for the different almanac stars can be easily interpolated, with sufficient accuracy for this purpose. Or the factors may be taken out of some general table computed with the arguments, zenith distance, $\varphi - \delta$, and declination. Such a table, computed by Professor Davidson, has been published in pamphlet form by the U. S. Coast and Geodetic survey.*

The observer will, of course, be restricted to the use of those stars for which the apparent right ascensions are given in the Almanac.

The "American Ephemeris and Nautical Almanac" may be procured from the Nautical Almanac Bureau, Washington, two or three years in advance, for the advertised price. It contains the apparent places of 451 stars. It is a first class plan to enter all the stars suitable for the observer's instrument, in a firmly bound blank book (which will open flat), as a working list; with ap-

* U. S. Coast Survey, 1874, "The Star-factors A, B, C, for Reducing Transit Observations."

proximate Right Ascension, Declination, and Magnitude; and with columns for "zenith distance," "setting," and the factors "A," "B," and "C."

We will now take up the process of reduction, step by step.

1. Find for each star, the time of transit across the "mean wire," which will be simply the average of the transits noted over each separate wire. If the wires are equally distant (and of an odd number, as they should be), this will be the time of transit over the middle wire, within the errors of observation. In this case, if one or more of the wires have been missed we can determine the mean from the first and last, second and penultimate, etc. More properly, we must compute the mean, using the known equatorial intervals, from the following formula:

$$t = \text{mean of observed threads} + \frac{\text{sum of equat. ints. of missed thrds.} \times \text{Sec Dec.}}{\text{number of obsd. threads.}}$$

Sec δ will be recognized as C, the collimation factor, but in multiplying by the natural number it should be carried out to three or four decimal places.

II. Find from the Almanac (pages 302—377), and enter in the record, the apparent right ascension of each star observed, for the night of observation.

III. Rate. If the rate of the time-piece is large (say over $2\frac{1}{2}^s$ daily), apply a correction to the mean thread of each star, to reduce all the observations to the same epoch (usually the mean of the R. A.'s of the time stars) let T be the time of transit of the star, and M, the middle time adopted, and let r be the rate of the clock per hour, + when the chronometer is losing, and — when gaining. Then will the correction for each star be equal to $(T - M)r$

IV. Level. The level constant b is found directly from the level readings as follows:

Let W, E be the west and east readings of the level.

W', E' be the west and east readings of the level when reversed.

d the value of one division of the level scale in seconds of arc.

Then $b = \frac{1}{4}\Big[(W + W') - (E + E')\Big]\frac{d}{15}$. The inequality of the pivots, if known, is to be applied directly to this quantity b; the inequality tending to increase $+b$ on one side of the clamp, and to diminish it on the other. Call this corrected level constant b', then is $b'B$ the correction to the observed time of transit of each star for level error.

Note.—The constant b' is always + (positive) when the *west end is too high*; and always—(negative) when the *east end is too high*,—in each case after the proper application of the correction for inequality. The factor B is considered + (positive) for *every* star except one observed *sub-polo*, when it becomes negative.

V. We have now corrected each observed transit for rate and for level error, and this has been done by means of constants directly observed; call the time of transit corrected for these two errors, t.

Then (the tabular right ascension being represented by R. A.), if the instrument were exactly adjusted for collimation and azimuth, the differences (R. A. — t) for each star would contain only the correction to the time-piece, and these differences would vary only by small fractions of a second, representing the accidental errors of observation. But each difference (R. A. — t) contains, besides the clock correction, the combined effect of the errors of collimation and azimuth on the observed transit of that particular star; and our task is now to compare all these separate results with a view to eliminate these two errors. We will call the collimation constant c (which is the amount in seconds of time that an equatorial star would be "out of collimation"), and we will call the azimuth constant a (which represents the amount an equatorial star would be deviated from the true meridian, measured on the horizon).

In computing the observations by the method of least squares we would form as many equations as there were stars observed, and thence derive the three unknown quantities, namely, c, a, and ΔT (the last being the error of the time-piece). Instead of this we will arrive at the instrumental constants by approximation.

Collimation.—If there is no way of assuming c from previous nights' observations we must derive an approximate value from the "time stars." In each position of the instrument clamp E., and clamp W., we have observed one "azimuth star" more or less close to the Pole, and two or three (or perhaps more) "time stars" more or less close to the zenith. Take the average (R. A. — t) for all the "time-stars" clamp E., and the same for clamp W. Then, if the average declination of the stars used is about the same for both sides, any difference between the mean (R: A. — t) E. and the mean (R. A. — t) W. is caused by error of collimation, and this difference will contain the average collimation error of the time stars on *both* sides of the clamp. Therefore, to assume a value for c, we must divide the difference above noted by average C. E. + average C. W. Then will cC be the ap-

proximate collimation correction for each star, which must be added to the time of transit on one side of the clamp, and subtracted on the other; we can either determine by simple inspection which this should be, or else follow (with careful regard to the algebraic signs, the annexed

Rule: For collimation constant, clamp east,—

When (R. A. — t) E — (R. A. — t) W is $\pm$, cE is also $\pm$.

VI. We have now applied to the time of transit the corrections for level, rate and collimation; call this corrected time t', then will (R. A. — t') for each star contain both the error of the time-piece and the azimuth error. Our object is now to eliminate the azimuth error: that is, to find a, and then by means of the factor A apply to each star a farther correction aA, leaving us t'' for the corrected time of transit, when finally (R. A. — t'') will give us the error of the time-piece, or ΔT.

To do this, the observations Clamp E. and Clamp W should be treated separately by the computer because a small instrument is very liable to change in azimuth upon reversal. A value of a is thus determined for each side of the clamp. Either may each "time star" be compared with the azimuth star in turn, and a value for a on that side of the clamp deduced from each separate comparison (the average value being finally adopted); or, what is simpler and amounts to the same thing, an average value of (R. A. — t', for the "time stars," with an average factor A, may be compared with the result by the azimuth star.

RULE TO FIND A. Take the average (R. A. — t') for the time stars, and from this subtract the value of (R. A. — t') given by the azimuth star. Subtract the factor A of the azimuth star from the average of the factors A of "the time stars." Divide the first of the above results by the second, the quotient will be a for that side of the clamp. Then compute aA for the last correction to the observed time of transit of each star. All this (and in fact every step in the computation) must be done with careful regard to the algebraic signs.

CHECK: *If the foregoing has been accurately done, the chronometer correction, or (R. A. — t''), as given by the "azimuth star" will be exactly equal to the mean (R. A. — t'') of the "time-star."*

In a similar manner determine a value for a, and resulting azimuth corrections to each star on the other side of the clamp, checking the work as before.

Take the mean result from the stars W. and mean result from the stars E.—(if the collimation error adopted was not far from the truth, these two values will be sensibly the same)—and the

mean of these two values will be the required error of the chronometer, or $\varDelta T$.

GENERAL NOTES.

(1) The constant c changes sign with reversal: the factor C is positive for every star except one observed *sub-polo*.

(2) A negative valve for a, indicates that the instrument is pointing to the west of south. The factor A is positive for all stars except those between the zenith and the pole.

(3) Any difference between the results for $\varDelta T$ obtained from the two sides of the clamp is caused by a wrong approximation to c.

Since cC is added on one side, and subtracted on the other any small error in assuming the constant is eliminated in taking the mean $\varDelta T$ from E. and W. stars. A large error in the approximation would derange the results for a on the two sides (and consequently the results for $\varDelta T$), hence if the difference is greater, say, than $0^s.15$, it will be well to repeat the latter part of the computation with a closer value for c.

(4) A difference is to be expected, in small instruments, between aE and aW. It is almost impossible to reverse the transit without disturbing the azimuth, either by jarring the supports, or relieving strain in some part of the instrument.

In computing the mean thread of the first and third stars in the preceding set, it was necessary to use the "equatorial intervals," which were known to be as follows (I being the thread first reached by an equatorial star when clamp was E).

$$\begin{aligned}
\text{I} &= -45^s.22\\
\text{II} &= -30\ .13\\
\text{III} &= -15\ .02\\
\text{IV} &= -00\ .06\\
\text{V} &= +15\ .03\\
\text{VI} &= +30\ .17\\
\text{VII} &= +45\ .24
\end{aligned}$$

[For clamp W. the sign changes.]

These, of course, represent the distance of each thread from the mean thread. Following the formula we have, in the case of ε Tauri

$$\frac{-45^s.22 \times 1.058}{6} = -07^s.98$$

the mean of the observed threads being $4^h\ 21^m\ 17^s.30$, we have, mean thread $= 4^h\ 21^m\ 9^s.32$.

Time Observations, San Francisco, Cal., March 5, 1886, p. m. Clock No. 3479. C. B. H.

STAR	ε Tauri.	α Tauri.	α Camel.	ε Aurigæ.	β Eridani.	α Aurigæ.	β Tauri.	966 Groom.
Clamp	E.	E.	E.	E.	W.	W.	W.	W.
Declination	+ 18° 56′	+ 16° 17′	+ 66° 9′	+ 43° 39′	− 5° 14′	+ 45° 53′	+ 28° 31′	+ 74° 58′
Factors. A	+ 0.34	+ 0.38	− 1.18	− 0.14	+ 0.68	− 0.20	+ 0.18	− 2.33
Factors. B	1.00	0.97	2.18	1.37	0.73	1.43	1.11	3.08
Factors. C	1.06	1.04	2.47	1.38	1.01	1.44	1.14	3.86
Levels E. and W.	19.5 21.0		21.5 24.0	27.0 19.5	23.5 25.0		18.0 32.0	18.2 33.2
	22.8 17.6		26.5 19.0	21.5 25.5	18.0 30.8		24.5 25.5	25.0 26.5
	42.3 38.6		48.0 43.0	48.5 45.0	41.5 55.8		42.5 57.5	43.2 59.7
Threads, I	—	47.3	—	56.6	41.2	22.5	25.3	44.8
II	37.6	03.1	—	17.5	56.4	44.2	42 6	43.0
III	53.4	18.9	—	38.0	11.5	05.9	59.5	41.5
IV	09.3	34.5	—	58.9	26.6	27.5	16.8	5 23 40.0
V	25.2	50.2	42 32.0	20.0	41.6	49.0	34.0	38.0
VI	41.1	05.9	43 09.0	40.7	56.8	10.5	50.9	36.2
VII	4 21 57.2	4 29 21.5	4 43 46.3	4 54 01.5	5 02 11.8	5 08 32.2	5 19 08.3	34.3
Mean Thread	4 21 9.32	4 28 34.49	4 41 54.54	4 52 59 03	5 01 26.56	5 07 27.40	5 18 16.77	5 23 39.69
Corrections. Rate.								
Corrections. Level.								
Corrections. Collim.								
Corrections. Azimuth.								
Corrected Mean								
Tabular R. A.	4 21 57.86	4 29 23.05	4 42 44.00	4 53 47.93	5 02 15.06	5 08 16.80	5 19 05.75	5 24 31.34
ΔT.								

Similarly for α Camelopardis we obtain,

$$4^h\,43^m\,09^s.10 - 1^m\,14^s.56 = 4^h\,41^m\,54^s.54.$$

Further we have:

Value 1 div. of level $= 1''.01$.

Inequality of pivots, $p = -1''.17 = -0^s.078$ (a very large value). Hourly rate of clock, $r = +0^s.10$.

The minus sign in the value of p shows that the clamp end is *too large*; this follows from the application of the formulæ given for the determination of pivot inequality (see report of the U. S. Coast and Geodetic Survey 1880, appendix No. 14, page 12).

We are now ready to reduce the time set by means of the preceding rules: first step, correction for *Rate*. Adopting 5^h sidereal (as the middle time) $= M$; we have for ε Tauri,

$$T - M = (4^h\,22^m) - (5^h\,00^m) = -0^h\,38^m, \text{ say } -0^h.7$$

Thence, $+0^s.10 \times -0.7 = -0^s.07$, which is the correction for rate to be applied to the time of transit of ε Tauri. In a similar manner we form the following corrections:

α Tauri $= -0^s.06$; α Camel. $= -0^s.03$; ε Aurigæ $= -0^s.01$; β Eridani $= 0^s.00$; α Aurigæ $= +0^s.01$; β Tauri $= +0^s.03$, and for 966 Groom. $= +0^s.04$.

Correction for Level.—In this example the level error has been determined for nearly every star; for α Tauri and α Aurigæ we may take a proportional value of the constant. [When the instrument is perfectly stable, it is preferable to use a mean value of b for each side of the clamp determined from all the readings taken on that side].

To compute the correction for ε Tauri we have

$$\frac{(W + W') - (E + E')}{4} = \frac{38.6 - 42.3}{4} = -0.925$$

$$\frac{d}{15} = 0^s.0673 \qquad -0.925 \times 0^s.0673 = -0^s.062 = b.$$

But from the value for "inequality of pivots," we know that the level will show clamp end too high by $0^s.078$. The clamp end in this case is E, which is *apparently* higher by $0^s.062$: in reality, then, the axis is elevated at the opposite end, and $b' = +0^s.016$. $B = 1.00$, and the level correction for ε *Tauri*, $b'B = +0^s.02$.

[The astronomer does not study out this relation between the apparent state of the level, and the "inequality," for the correction to each star observed, but determines a formula, once for all, and thereafter uses that formula without further mental effort. When p is —, we obtain the rule

Clamp West $+ b$ must be numerically diminished,

Clamp East, $+b$ must be numerically increased, and the reverse, when p is $+$.

Thus, for correction to 966 Groom., Clamp W, we have

$$\frac{59.7 - 43.2}{4} = +4.125 \qquad +4.125 \times 0^s.0673 = +0^s.278$$

But $+b$ must be numerically diminished, and $b' = +0^s.200$, and $b'B = +0^s.62$].

The level corrections for all the stars are:—

ε Tauri $= +0^s.02$ α Tauri $= +0^s.02$ α Camel. $= -0^s.01$
ε Aurigæ $= +0.03$ β Eridani $= +0.12$ α Aurigæ $= +0^s.24$
β Tauri $= +0.19$ 966 Groom. $= +0.62$

Correction for Collimation.—The mean thread corrected for the two preceding errors we have called t. We now take out R. A. $- t$ for each "time-star".

Clamp E.			*Clamp W.*	
R. A. $- t =$	$+48^s.59$	$C = 1.06$	R. A. $- t = +48^s.38$	$C = 1.01$
	$+48.60$	1.04	$+49.15$	1.44
	$+48.88$	1.38	$+48.76$	1.14
Mean $=$	$+48.69$	1.16	Mean $= +48.77$	1.20

Then by the rule:

$$\frac{(+48^s.69) - (+48^s.77)}{1.16 + 1.20} = \frac{-0^s.08}{2.36} = -0^s.034$$

which is the resulting assumption for c on the east side (on the west side the sign of c is changed to $+$). The convenience in multiplying, and bearing in mind No. (3) of the "general notes," alone, we will assume $cE = -0^s.05$; and $cW = +0^s.05$.

From these we obtain the provisional collimation corrections which follow:—

ε Tauri $= -0^s.05$ α Tauri $= -0^s.05$ α Camel. $= -0^s.12$
ε Aurigæ $= -0.07$ β Eridani $= +0.05$ α Aurigæ $= +0.07$
β Tauri $= +0.06$ 966 Groom. $= +0.19$

[The correction for "diurnal aberration," usually included with the collimation constant, has been neglected.]

Correction for Azimuth—Having applied the corrections so far determined to the mean thread we form the annexed table:

Clamp......	E	E	E	E	W	W	W	W
Star..........	ε Tauri	α Tauri	(α Camel)	ε Aurig.	β Erid.	α Aurig.	β Tauri	(966 Gr.)
A..............	+ 0.34	+ 0.38	− 1.18	− 0.14	+ 0.68	− 0.20	+ 0.18	− 2.33
t'..........	09.22	34.40	54.38	58.98	26.73	27.72	17.05	40.54
R. A..........	57.86	23.05	44.00	47.93	15.06	16.80	05.75	31.34
(R. A. − t')	+ 48.64	+48.65	(+ 49 62)	+ 48.95	+ 48.33	+ 49.08	+48.70	(+ 50.80)

Then to find *a* for clamp East:

$$\frac{+48.64 + 48.65 + 48.95}{3} = +48^s.747$$

$= \text{average (R. A.} - t') \text{ of time stars.}$

$$\frac{+.34 + .38 + (-.14)}{3} = +0.193$$

$= \text{average } A \text{ of time stars,}$

and,

$$\frac{+48.747 - 49.62}{+.193 - (-1.18)} = \frac{-0.873}{+1.373} = -0^s.636, \text{ or } a \text{ for clamp E.}$$

In like manner we find a, clamp W., $= -0^s.822$.

Multiplying the constant, a, on each side by the factors, A, for each star on that side, we are enabled to apply the remaining correction with the following results for ΔT:—

Clamp E.

			Check:
(R. A. — t''),	ε Tauri	$= +48^s.86$	
	α Tauri	$= +48.89$	Time-stars $= +48^s.87$
	(α Camel	$= +48.87$)	Azimuth-star $= +48.87$
	ε Aurigæ	$= +48.86$	

Clamp W.

			Check:
(R. A. — t''),	β Eridani	$= +48.89$	
	α Aurigæ	$= +48.92$	Time stars $= +48^s.89$
	β Tauri	$= +48.85$	Azimuth star $= +48.88$.
	(966 Groom.	$= +48.88$)	

The mean of E. and W. gives us for the correction to the timepiece at 5^h sidereal or $\Delta T, = +0^m\ 48^s.88$, (*i. e.*, it is *slow* that much). The results from each side are so nearly the same that there is no need of any repetition (with an improved value of c), and this computation may be considered final.

In very few cases will it be necessary to repeat the computation unless there should be a large difference between the average declinations of the time-stars used in the two sides, or unless the instrument greatly changed its azimuth in reversing.

The successive steps in this process are tedious in detail, but the method of reduction once learned is very simple in practice. The complete reduction of a set of observations like the preceding need not consume over twenty minutes, or half an hour, when the night's record has been fairly completed and the star factors entered. A rigorous reduction of the same observations, by the method of least squares, will give identical results.

I can claim no originality whatever for the method of reduction herewith presented. It is due, I believe, to the Computing Division of the U. S. Coast and Geodetic Survey. The method of successive approximations (one freqently used in astronomical reductions) may appear at first sight like "forcing" the results; but it is perfectly legitimate to adopt such values for the instrumental constants as will best satisfy the observations.

San Francisco, Cal., January, 1893.

ASTRO-PHYSICS.

THE WORK OF KAYSER AND RUNGE ON THE SPECTRA OF THE ELEMENTS.*

JOSEPH SWEETMAN AMES.

In a series of papers†, appearing at intervals of about a year, and beginning in 1888, Kayser and Runge, professors of Physics and Mathematics, respectively, in the Hochschule in Hannover, have published the results of a most elaborate and interesting investigation of the spectra of the elements. The work is by no means completed yet, but the results so far attained are most worthy of attention.

They began their investigation from the desire to study the regularities of the various known spectra: the systematic distribution of lines in any one spectrum and the points of resemblance between the spectra of different elements. Many physicists and chemists had investigated both these subjects before; some particular laws had been discovered, but no general relations. The spectra, which even at first sight are open to simple mathematical study, are of two kinds: fluted or banded ones like those of carbon or air; and those containing series of lines which have similar physical properties and which are so distributed as to almost obviously belong together. Liveing and Dewar had called attention to many spectra of this second kind, including those of lithium, zinc and others. The law of arrangement of lines in the fluted spectra was discovered at about the same time by several people, but the first to announce it was Deslandres. It is

$$\frac{1}{\lambda} = a + bn^2; \qquad n = 0, 1, 2, 3, \text{ etc.}$$

Stated in words, the second differences of the wave-frequencies are constant for a given band. This formula agrees fairly well with even the latest and best measurements. Deslandres also announced a law connecting the different bands in the same spectrum; and, although it does not seem to be verified by the results of Kayser and Runge, yet it may serve to decide in which group of bands a doubtful one belongs. It was not until 1885 that any simple mathematical formula was found which would express the arrangement of the lines in a spectrum of the second

* Communicated by the author.

† Ueber die Spectren der Elemente von H. Kayser und C. Runge, Berlin, 1888-1892.

kind. But in that year Balmer published the following empirical formula for the line spectrum of hydrogen,

$$\lambda = \lambda_0 \frac{n^2}{n^2 - 4}; \qquad n = 3, 4, 5, \text{etc.}$$

This formula agrees wonderfully with the results of experiment. There is such a marked resemblance between all the spectra of the second kind that Kayser and Runge proposed applying a slight extension of Balmer's formula to them. Several modifications, such as

$$\frac{1}{\lambda} = A + Bn^{-1} + Cn^{-2}$$

$$\frac{1}{\lambda} = A + Bn^{-2} + Cn^{-4}$$

were tried. To test these, most accurate measurements of the wave-lengths were needed. A careful comparison of the results of previous investigators showed at once such discrepancies and uncertainties that it was decided to make a new determination of the wave-lengths of the spectra of as many of the elements as possible.

Various plans were discussed and tried, and the method finally adopted was that of Rowland, a concave grating mounted with fixed slit. The spectra were produced in general by an arc-light whose carbon poles were bored and filled with some salt of the element under consideration. One great advantage thus secured is that the results obtained are to a certain degree comparable as to temperature and other conditions. The spectrum of iron was chosen as the standard one, with which all others were to be compared, and the wave-lengths of its lines were determined by a series of measurements, made under various conditions, Bell's final value of the *D* lines being accepted as correct. Hence, Kayser and Runge's observations can be at once compared with Rowland's for their scales are identical. The spectra of other elements were then photographed on the same plate with corresponding portions of the iron spectrum, and the wave-lengths of the lines could then be determined by interpolation. All these final measurements were made on a dividing engine which had been specially constructed for the purpose; and the observations were then reduced by the method of least squares.

Since the spectra of carbon and its impurities must, owing to the nature of the process, appear on all the plates, the first step in the enormous undertaking was to determine the lines of the carbon spectrum itself. It consists, as is well known, of a number

of fluted bands, in many cases overlapping. Kayser and Runge found as the result of careful study that for all the bands the formula

$$\frac{1}{\lambda} = a + be^{cn}(\sin dn^2)$$

expressed the arrangement of the lines almost perfectly, while Deslandres' law did fairly well for lines near the beginning of the bands. The question as to the origin of these bands, *i. e.* whether they are due to carbon itself or to some of its compounds such as cyanogen, still remains unsettled. Kayser and Runge have however, thrown important light on the subject, by separating the bands into two groups, and showing that those beginning at 4216.12, 3883.55 and 3590.48 have some intimate connection with the presence of nitrogen in the arc. The difficulty lies in the fact that all these bands are present in the spectrum of the Sun, which proves that if they are due to a compound of carbon and nitrogen, it must be one which is stable at enormously high temperatures, and which is probably unknown to us on the earth.

As soon as the lines in the carbon spectrum had been identified, a systematic investigation of the other elements, based upon their arrangement in Mendelejeff's table, was begun. It was soon found that that modification of Balmer's formula for hydrogen which best fitted the series in the spectrum of the other elements was

$$\frac{1}{\lambda} = A + Bn^{-2} + Cn^{-4}$$

where A, B, and C were determined for any one series by the method of least squares. It was also found that each spectrum contained at the most three series, each distinguished by the physical peculiarities of its lines. Kayser and Runge describe these series as follows: the main series whose lines are sharp, distinct, and easily reversed; the first subsidiary series, whose lines are strong, diffuse and easily reversed; the second subsidiary, whose lines are faint, sharp or diffuse on one side only, and never reversed. They give reasons for thinking that the main series is brought out by high temperatures, while the subsidiary ones are produced at comparatively low temperatures.

Considering the elements in detail, lithium, sodium, potassium, rubidium, and caesium have the three series, and all except lithium have the lines of the main series appearing in pairs, *i. e.*, each series is made up of two series, any one line having another associated with it. The subsidiary series of sodium and potassium

also are composed of pairs. Copper and silver have the two subsidiary series, also made up of pairs; while gold has no series; but each of the three possess in the ultra-violet an isolated pair, the strongest lines in the spectrum of each. In the second column of Mendelejeff's table the elements arrange themselves from a spectroscopic standpoint into two groups: magnesium, calcium and strontium; zinc, cadmium and mercury. Each of these elements has only the two subsidiary series, made up now of triplets. Further, zinc, cadmium and mercury, each, has in the ultra-violet, as the strongest line in its spectrum, an isolated single line, thus showing an analogy to copper, silver and gold. Magnesium also has a single isolated line, being connected thus with zinc and cadmium, as was to be expected from its chemical properties. Barium has no series.

Of the other elements only aluminium, indium, and thalium have been carefully studied. Each of them has the two subsidiary series, made up of pairs; and for any one element the two series seem to end at almost the same point.

In any one of the subsidiary series made up of pairs or triplets, the differences between the wave frequencies of the members of the pairs is fairly constant; and, if we follow any one series through the spectra of the same group, there is a general connection between this characteristic difference and the atomic weight of the element.

There are certain peculiarities to be noted, common to all the series of any one group. If we observe the formulas

$$\frac{1}{\lambda} = A + Bn^{-2} + Cn^{-4}$$

which represent any one series in the different elements, *e. g.*, the first subsidiary; it is noticed that as the atomic weight increases A decreases, *i. e.*, the series are shifted toward the red end of the spectrum. B, on the other hand, remains practically unchanged. As we pass from the elements in the first of Mendelejeff's columns to the higher ones, it is noticed that A increases, *i. e.*, corresponding series recede towards the ultra-violet; while B changes only a little. This shifting of the series may account in part for the vanishing of some of the series in certain of the elements.

It was not to be expected, nor was it observed, that in all cases all the lines of any one spectrum form members of series. In general the larger proportion of the lines seem to be distributed entirely arbitrarily. Kayser and Runge note a most interesting connection between the melting-point of an element and the ratio which the number of series-forming lines bears to the

whole number of lines in its spectrum. The higher the melting-point the less as a rule is this ratio. For instance, barium, with its high melting-point, has no series; while lithium, sodium and several other elements, which have low melting-points have all their lines distributed in series. The explanation given by Kayser and Runge is a natural one. The presence of a series in the spectrum of an element shows that the molecule is vibrating in some natural, unconstrained way; and this state can be reached only at temperatures far above the melting-point. Hence, at the temperature of the arc, we should expect series only in those elements which melt at low temperatures. Kayser and Runge think that the main difference between the arc and the spark-spectra is one of temperature; and it is to be hoped that this question will soon be settled. In their last paper (1892) Kayser and Runge describe the results of an investigation of the cause of the apparent stopping of all spectra at about w. l. 2000. They show quite conclusively that this is due, not to absorption by the air or by the grating, but to the action of the grained structure of the photographic films. Herr Schumann of Leipzig is said to have overcome this difficulty, and to be able to photograph as far as w. l. 1000. But unfortunately, he has not published an account of his method.

In commenting upon this work of Kayser and Runge, so far as published, nothing but praise is their due. A higher degree of accuracy has been reached than ever before; most interesting relations have been shown to exist between the lines of any one spectrum, and between the spectra of different elements; credit has been bestowed upon all other investigators; and most complete descriptions of apparatus and methods are given. It is possible that too much importance is laid upon the exactness of the mathematical relations to be expected, but this is not offered as a criticism. One misses a full consideration of certain questions, such as the presence of an element in the Sun, the cause of the anomalous difference in intensity between a line produced in the arc and the corresponding solar line, *e. g.*, some of the calcium lines; but these may well be regarded as beyond the limits which Kayser and Runge have set to their investigations. It is most earnestly to be hoped that their work will continue without any serious hindrance, and be extended to rarer elements, especially to the so-called "rare-earths."

ON THE REFRACTION OF RAYS OF GREAT WAVE-LENGTH IN ROCK-SALT, SYLVITE AND FLUORITE.*

H. RUBENS AND BENJAMIN W. SNOW.

In the 40th Vol. of Wiedemann's Annalen one of the present authors recently described a method whereby a knowledge of the dispersion of rays in the infra-red may be easily obtained. With the aid of this device, the dependence of the index of refraction upon the wave-length was determined for 16 materials, viz.: for 9 different samples of glass, for water, carbon-di-sulphide, xylol, benzol, quartz, rock-salt and fluorite. Inasmuch as in this paper a minute description is given of the methods employed, it will suffice here briefly to refer to the main features of the method of procedure followed in the present determination.

The rays from the zirconia burner of Linnemann, after being reflected from the front and the rear surfaces of a thin plate of air enclosed between two parallel glass planes, were then concentrated upon the slit of a spectrometer, by which means two beams of light were produced capable of mutual interference, so that the otherwise continuous spectrum of the incandescent zirconia plate was crossed by a series of vertical interference bands. The wave-length λ of each such dark band, multiplied by a certain whole number m, always equals the product of twice the thickness d of the layer of air and the cosine of the angle of incidence i of the rays. With the aid of the Fraunhofer lines, the wave-lengths of the interference bands were determined for the visible portion of the spectrum, and from this data were calculated the order m of each dark band and the product $K = 2d \cos i$. The knowledge of these two constants proved then sufficient to determine also the wave-lengths of the interference bands in the infra-red. The positions of these latter were obtained by allowing the sensitive filament of a linear bolometer to wander through the spectrum, and plotting the observed galvanometer deflections as a function of the angular deviation. The interference bands were then recognized as minima or maxima in the curve. In this way, for a series of angular deviations may be obtained the corresponding indices of refraction, that is a number of points in the $n - \lambda$ plane may be determined, which, when joined by a smooth curve, give the curve of dispersion for the material examined.

* Communicated by the authors. Translated from Wiedemann's Annalen, Vol. 46, 1892.

In the majority of the bodies thus investigated, the limit of the region of the infra-red capable of being explored was prescribed by the absorption which increases rapidly with increasing wave-length. In two cases alone, viz.: when working with rock-salt and with fluorite did we discontinue the observations at wave-lengths $\lambda = 5.7\mu$ and $\lambda = 3.3\mu$ respectively before the region of strong absorption was reached. This was rendered necessary by the fact that the apparatus employed proved to be insufficiently sensitive to measure the exceedingly feeble energy found in the spectrum of the zirconia burner at these long wave-lengths.

As a means of continuing the investigation beyond this point, two ways of improvement suggested themselves. At first we thought it possible to increase the energy of the source of light, but all endeavors to attain this end proved of no avail. The use of the electric arc for this purpose, after a short but thorough trial, was discontinued. Even arc lamps of unusually good regulation, when supplied by the almost perfectly constant current of the Berlin central station, gave a radiation too fluctuating to be used in place of the zirconia light. The regulation of the arc by hand was also tried, but likewise without success. The use, moreover, of a zirconia burner of nearly double the dimensions of the former resulted in only a feeble increase in the energy, while a series of new difficulties was thereby introduced, such as the melting of the platinum cell, a greater consumption of gas, etc. We concluded, therefore, for the further investigations, to retain the source of light in its original form, and to make better use of the energy here at hand by increasing as far as possible the sensitiveness of the measuring apparatus.

The first change toward the accomplishment of this end was effected in the substitution of two plane surfaces of larger dimensions in place of the reflecting plates formerly used. For this purpose the optical firm of Carl Zeis, of Jena, most generously provided us with two plates with plane surfaces 4 cm. square and 1 cm. thick, one of crown glass and the other of fluorite. The plates were set in metal frames, and the distance between them regulated by a system of screws, as in the former case. With the exception of the extreme edges, both plates were ground to a truly plane surface. A rectangular opening in a diaphragm placed in the path of the rays allowed only that light to enter the slit of the spectroscope which had been reflected from the central portion of the plates. The interference bands thus produced were unusually sharp, as can be seen from the pronounced minima of the curves in Figs. 1, 2 and 3, which represent the three different en-

ergy spectra. Hardly need it be mentioned that in the following experiments the entire optical system consisted entirely of rock-salt and fluorite.

The delicacy of the bolometer was increased chiefly by using a galvanometer of the highest degree of sensitiveness, which one of us had constructed, and which has been described in detail in a recent paper.* The coils of the galvanometer, when in series, amounted in resistance to 140 ohms; and when the period of the needle was reduced for the single swing to 10 seconds, 1 mm. deflection on the scale indicated a current of 1.3×10^{-11} ampère. With this degree of astaticism the zero point of the needle was perfectly constant. The bolometer with which the following determinations were made is described in the previous paper as No. 2. It consisted of two strips of platinum 12 mm. long and $\frac{1}{12}$ mm. wide, each having about 80 ohms resistance, only one of these being exposed to radiation. With the aid of the new galvanometer we were able to reach a sensitiveness of 0.000003° C. per mm. deflection. A standard candle one meter distant produced a deflection of 400 mm.

With the exception of the changes here mentioned, all pieces of apparatus were identical with those formerly described. The relative positions, moreover, of the instruments, as well as the manner and the order in which the operations were made, were retained unchanged. We can, therefore, pass at once to the results of our observations.

Measurements were made upon three materials well known for their diathermous properties, rock-salt, sylvite and fluorite.

I Rock-Salt.

We had at our disposal a prism of this mineral having a triangular base 3½ cm. on each side and 4½ cm. in height. Before being used, the prism was freshly polished and its refracting angle redetermined. The observations with the bolometer gave the energy spectrum represented in Fig. 1. The positions of the maxima and the minima were corrected, as in the paper cited above, with the aid of the enveloping curve whereby the points of contact of the two curves were used without further modification as the characteristic points in question. As the theory shows, this method gives a closer approximation to the quantities required than the method by construction given in the former paper. But little weight, however, is to be attached to the su-

* Benjamin W. Snow, Wied. Ann., Vol. 47, p. 216, 1892.

periority of this modification, as both methods lead to results which are identical to the fourth decimal place.

Inasmuch as the present investigation was undertaken expressly for the purpose of extending measurements as far as possible in the infra-red, we were compelled to use a comparatively thick layer of air for reflecting the interfering beams of light, which brought the interference bands in the spectrum very near together. It was, however, quickly found that even the narrow width of the bolometer and the impurity of the spectrum, caused by the aberration of the lenses, placed a limit beyond which the further reduction of the breadth of the interference bands could not be carried. With the feeble dispersion of the materials used, this limit was practically reached when the visible spectrum was crossed by seven or eight interference bands, which gave a value to the constant $K = 2d \cos i$ of about 8.5μ. According to this, the minimum of the first order, which is the farthest possible allowable point in the infra-red, has the wave-length $\lambda = 8.5\mu$. Then follow the maximum of the second order, and the corresponding minimum, which have wave-lengths $\lambda = 5.7\mu$ and 4.3μ respectively. Although the curvature of the curve of dispersion in this region is slight, it seemed to us nevertheless desirable to add for greater accuracy in our measurements other possible points to the small number already obtained. In order to attain this end, we found it advantageous to use not only the corrected positions of the maxima and minima and the corresponding wave-lengths for plotting the curve of dispersion, but also the points of intersection of the energy curve, $G = f(\alpha)$ (see Fig. 1), with the curve of mean energy, $R = f(\alpha)$, since the wave-lengths corresponding to the abscissæ of these points are easily calculated. This latter curve might have been observed, directly had the distance between the plates enclosing the reflecting layer of air been sufficiently increased.

This curve, $R = f(\alpha)$, which expresses the distribution of energy when no interference is present, can be constructed, however, with sufficient accuracy, when at each point an ordinate is erected equal to the mean of the ordinates of the corresponding points in the envelopes P and Q. If the curve $G = f(\alpha)$ is intersected at any point by the curve $R = f(\alpha)$, then the amplitude for the abscissa of this point must have the same magnitude which it would have attained had a superposition of the energy of the two beams taken place without interference.

The vibratory motion of the two beams whose amplitude and period are A and T respectively, may be represented by the equation:

$$y_1 = A \sin 2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)$$

$$y_2 = A \sin 2\pi\left(\frac{t}{T} - \frac{x + K + \frac{\lambda}{2}}{\lambda}\right)$$

They unite to form the ray:

$$Y = 2A \cos \frac{\pi\left(K + \frac{\lambda}{2}\right)}{\lambda} \sin 2\pi\left(\frac{t}{T} - \frac{x + \frac{K}{2} + \frac{\lambda}{4}}{\lambda}\right)$$

$$= 2A \sin \frac{\pi K}{\lambda} \sin 2\pi\left(\frac{t}{T} - \frac{x + \frac{K}{2} + \frac{\lambda}{4}}{\lambda}\right)$$

It follows from what has been said above that for the abscissa of the point of intersection of the two curves, R and G, the amplitude of the beam Y, viz.: $2A \sin \frac{\pi K}{\lambda}$, must equal $\pm A\sqrt{2}$. λ is accordingly determined from the equation

$$\sin \frac{\pi K}{\lambda} = \pm \tfrac{1}{2}\sqrt{2}.$$

$$\frac{\pi K}{\lambda} = \frac{\pi}{4}, \frac{3\pi}{4}, \frac{5\pi}{4} \cdots \frac{(2n+1)\pi}{4}$$

where n is any whole number. The wave-length, therefore, of each point of intersection is given by the equation:

$$\lambda = \frac{4K}{2n+1}.$$

A knowledge of the order of the adjacent maxima and minima gives at once an interpretation to the quantity n. If the point of intersection in question lies in such a way that the adjacent minimum (mth order) lies on the side of the longer wave-lengths and the adjacent maximum on the side of the shorter wave-lengths, then $n = 2m$.

The introduction of these points in the calculation of the curve of dispersion made it possible for us to conduct the observations with interference bands as broad as were necessary, and at the same time to obtain a sufficiently great number of points to enable us to ascertain the character of the curve of dispersion in the extreme infra-red with nearly the same degree of accuracy as in those portions of the spectrum lying but little beyond the reach of the eye.

At this point mention should be made of a peculiarity of the en-

ergy curve which may be observed in the drawing (Fig. 1). The deflections of the galvanometer, at the point of the last minimum a_{11}, not only sink to zero, but even assume negative values. The cause of this singularity, which also appears to a smaller degree in the energy curve of fluorite, is to be found in the fact that the second, unilluminated arm of the bolometer, which was placed in the apparatus within a casing of hard rubber, received upon its surface, notwithstanding this covering, a greater amount of energy than the first arm, which was exposed to the direct radiation. The plausibility of this explanation is increased when we remember that the covered resistance is then at a portion of the spectrum in which the mean energy is 50 times greater than in the neighborhood of the minimum a_{11}, and that ebonite is not opaque to thermal radiations of great wave-length.

In the following table are found the results of the observed indices of refraction and wave-lengths. The first column entitled "Name," gives the quality of the characteristic point in question, as Fraunhofer line, minimum (a), maximum (b), or point (c) of intersection of the curves G and R; the second column contains the angle of deviation α, as measured on the graduated circle; the third contains the index of refraction n, calculated from the refracting angle φ and the angle of deviation α according to the formula

$$n = \frac{\sin \frac{\varphi + \alpha}{2}}{\sin \frac{\varphi}{2}};$$

the fourth column contains finally the wave-length, which is calculated from the order m of the interference band and the constant $K = 2d \cos i$. The curve of dispersion plotted from the data of this table is found in Fig. 4*a*.

TABLE I.

Refracting Angle of the Rock-salt Prism, $\varphi = 60° 2'$;
$K = 8.307\mu$; a_1 is the 11th order.

Name	α °	′	n	λ	Name	α °	′	n	λ
H_γ	42	37	1,5607	0,434μ	b_3	40	2½	1,5321	0,978μ
F	41	56	1,5531	0,485"	a_4	39	58	1,5313	1,035"
D		7	1,5441	0,589"	b_4		54½	1,5305	1,107"
C	40	47	1,5404	0,656"	a_5		51	1,5299	1,186"
a_1		29	1,5370	0,755"	b_5		47½	1,5293	1,277"
b_1		22½	1,5358	0,790"	a_6		44	1,5286	1,384"
a_2		16½	1,5347	0,831"	b_6	39	41	1,5280	1,511"
b_2		11½	1,5337	0,876"	a_7		38	1,5275	1,660"
a_3		7	1,5329	0,923"	b_7		35	1,5270	1,845"

TABLE I—*Continued.*

Name	α °	′	n	λ	Name	α °	′	n	λ
a_8	39	32	1,5264	2,076μ	a_{10}	39	2	1,5208	4,150μ
b_8		28	1,5257	2,372"	c_3	38	56	1,5197	4,745"
a_9		22½	1,5247	2,771"	b_{10}		49	1,5184	5,540"
c_1		18	1,5239	3,022"	c_4		37½	1,5163	6,647"
b_9		13½	1,5230	3,320"	a_{11}		24	1,5138	8,307"
c_2		7	1,5217	3,690"					

It is well known that Professor Langley,* by a method wholly different from the one here described was able to follow the dispersion in rock-salt to a wave-length $\lambda = 5.3\ \mu$. He found in these experiments that the curve of dispersion from about $\lambda = 2\ \mu$ on followed very nearly a straight line. Owing to the fact that even with the elaborate means at hand he was unable to extend measurements by his method further than this in the direction of the long wave-lengths, he concluded to extend this straight line throughout the still more distant region of the infra-red in which his observations were taken. Many theoretical objections are at once suggested by so extensive an exterpolation. Among these criticisms may be mentioned one in particular, that from a definite wave length on, the indices of refraction would assume negative values, which at once points to an utter impossibility. There remained, however, the possibility that, within the limits of Professor Langley's measurements of energy, the straight line exterpolation gave results which were at least a first approximation to the true value. A glance at curve, Fig. 4*a* shows, on the other hand, that in reality this is not the case. Indeed it is true that our own curve of dispersion tends toward a straight line until a point is reached almost as distant as $\lambda = 5\ \mu$; but at $\lambda = 5\ \mu$ the curve begins gradually to lessen its inclination to the horizontal axis of wave lengths, and at $\lambda = 8\ \mu$ the effect of this curvature is so considerable that a straight line exterpolation from $\lambda = 5\ \mu$ on to this point would introduce an error in the determination of wave-length not less than 1μ.

In the following table a comparison is made between our results and those of Professor Langley. It is to be noticed that his curve, so far as this is plotted from his observations, agrees fairly well with our own, but that his values obtained by exterpolation differ widely from those observed by us, and that this difference increases as the wave-length becomes longer. There is also added here for completeness the data obtained from the previous paper. That an easier comparison may be made with Langley's figures, the wave-lengths selected increase by multiples of $\lambda_D = 0.589\mu$.

* Langley, Ann. de Chim. et de Phys. (6) 9, p. 433, 1886.

TABLE II.

Wave-Length	n (Langley)		n (Rubens)	n (Rubens & Snow)	n (Langley) — n (Rub. & Sn.)
$1\ \lambda_D = 0{,}589\mu$	1,5442	Observed	1,5441	1,5441	0,0001
$2\ \lambda_D = 1{,}178$ "	1,5301		1,5300	1,5301	0
$3\ \lambda_D = 1{,}767$ "	1,5272		1,5269	1,5272	0
$4\ \lambda_D = 2{,}356$ "	1,5254		1,5253	1,5256	− 0,0002
$5\ \lambda_D = 2{,}945$ "	1,5243		1,5241	1,5240	+ 0,0003
$6\ \lambda_D = 3{,}534$ "	1,5227		1,5227	1,5226	1
$7\ \lambda_D = 4{,}123$ "	1,5215		1,5214	1,5212	3
$8\ \lambda_D = 4{,}712$ "	1,5201		1,5202	1,5200	1
$9\ \lambda_D = 5{,}301$ "	1,5186		1,5189	1,5188	− 0,0002
$10\ \lambda_D = 5{,}890$ "	1,5172	Extrapolated	—	1,5177	5
$11\ \lambda_D = 6{,}480$ "	1,5158		—	1,5167	8
$12\ \lambda_D = 7{,}070$ "	1,5144		—	1,5158	13
$13\ \lambda_D = 7{,}66$ "	1,5129		—	1,5146	19
$14\ \lambda_D = 8{,}25$ "	1,5115		—	1,5138	23

The values, therefore, attributed by Professor Langley* to the wave-lengths in that region of the spectrum lying between $\lambda = 0$ and $\lambda = 5\mu$ are undoubtedly correct. Beyond this limit, however, at least as far as $\lambda = 8.3\mu$, the values assumed are too small, but it is not impossible that when still greater wave-lengths are reached the sign of the error may change. The results, nevertheless, of his observations remain of the greatest interest, since it will be easily possible to apply a correction to the wave-lengths, as soon as the dispersion in rock-salt can be followed to sufficiently small indices of refraction.

SYLVITE.

The behaviour of rock-salt is in every respect similar to that of the mineral sylvite, to which it stands in close chemical relation. There was placed at our disposal a prism of this material 14 mm. at the base and 20 mm. in height, whose surfaces were so well polished that the refracting angle could be determined to within 0.5 minutes.

In Fig. 2, the observed galvanometer deflections are plotted as a function of the angular deviation of the bolometer arm. From this curve is computed the table of dispersion in the manner described above. Corresponding to this is plotted the curve of dispersion Fig. 4[b]:

* Langley, Sill. Jour. (3) 31, p. 1-12. 1886, further (3), 32, p. 83-106, 1886 and (3), 38, p. 421-440. Phil. Mag. 26, p. 505, 1888. The same is true of the papers of Angström, Öfversigt af Kongl. Vet. Akad. Förhandl. 9, p. 549, 1889, and 7, p. 331, 1890, and W. H. Julius, Arch. Néerl, p. 310-384, 1888.

TABLE III.

Refracting Angle of the Sylvite Prism $\varphi = 59° 54'$.
$K = 8.022\mu$; a_1 is 10th order.

Name	α °	α ′	n	λ	Name	α °	α ′	n	λ
H_γ	37	30	1.5048	0.434μ	b_5	35	5	1.4766	1.458μ
F	36	55	1.4981	0.486"	a_6		2½	1.4761	1.603"
D		13½	1.4900	0.589"	b_6	34	59½	1.4755	1.781"
C	35	57	1.4868	0.656"	a_7		56½	1.4749	2.005"
a_1		37	1.4829	0.802"	b_7		53	1.4742	2.291"
b_1		32	1.4819	0.845"	a_8		48	1.4732	2.673"
a_2		27	1.4809	0.893"	a_8		43	1.4722	3.209"
b_2		23½	1.4802	0.944"	c_1		40½	1.4717	3.561"
a_3		20	1.4795	1.003"	a_9		38	1.4712	4.011"
b_3		16½	1.4789	1.070"	c_2		35½	1.4708	4.577"
a_4		13	1.4782	1.145"	b_9		32	1.4701	5.345"
b_4		10	1.4776	1.234"	c_3		28	1.4693	6.412"
a_5		7½	1.4771	1.337"	a_{10}		22	1.4681	8.022"

A study of this curve shows that the dispersion in sylvite which in the visible spectrum is only slightly inferior to that in rock-salt decreases in a similar manner but far more rapidly than in this latter mineral, so that at wave-length $\lambda = 8\mu$ its dispersion is only about one third part of the corresponding dispersion in rock-salt. Notwithstanding the great durability of this material and its permanence in moist air, as well as its almost perfect transparency to thermal radiations, the exceedingly rapid decrease in the dispersive power of sylvite renders this substance not so well adapted for experiments involving the use of prisms as rock-salt, whose surfaces are only with difficulty kept perfect. In the construction of condensing lenses this difficulty does not occur.

FLUORITE.

The prism here examined is the same one which was used in the former investigation. The value of the refracting angle was determined anew, and was found to agree very closely with the observations previously made.

For a long time we tried in vain to measure the energy spectrum produced by the fluorite prism beyond wave-length $\lambda = 3.5\mu$. The results of the previous investigation show the cause of our failure to be due to the fact that after a region of comparative feeble dispersion, the dispersive power of fluorite increases and the energy in this part of the spectrum becomes proportionally weaker. In order to make further advances, we were finally compelled to open wider the slit of the spectrometer at those places where the radiant energy sinks below a measurable quantity. The repetition of this device enabled us to reach a wave-length in the infra-red greater than $\lambda = 8\mu$. In the curve shown in Fig. 3,

which represents the observed distribution of energy produced by the fluorite prism, the slit was twice opened, the first time from 0.1 mm. to 0.4 mm. when the arm of the bolometer was at a deviation $\alpha = 30° \ 10'$, and a second time from 0.4 mm. to 1.0 mm. at the angle of deviation of $\alpha = 28° \ 50'$. By this means the deflections of the galvanometer were increased four fold and ten fold respectively. Owing to the greatly increased dispersion and the corresponding increase in the breadth of the interference bands, this change in the width of the slit did not materially interfere with the sharpness of the bands in this region of the spectrum. Inasmuch as only one side of the slit was movable, a correction had to be applied to the reading of the arm of the bolometer when the slit was opened.

The distribution of energy as shown in Fig. 3 gives a curve whose character is wholly different from the representation of the energy spectra produced by rock-salt or sylvite, given in Figs. 1 and 2. While in the latter, the breadth of the interference bands increases only slowly as the extreme infra-red is reached, amounting finally hardly more than to double the smallest value, the breadth of these bands varies, in the energy curve as given by the fluorite prism, from 5 minutes to more than 2½ degrees. Corresponding to this peculiar characteristic in the energy spectrum of fluorite the quality of the dispersion in this mineral is quite different from that of the material previously considered. In the following table, which contains this data, the indices of refraction are given only to three decimal places. As a result of the very considerable breadth of the interference bands, it is impossible to locate the positions of the characteristic points with the precision attainable in other cases.

TABLE IV.

Refracting Angle of the Fluorite Prism 59° 59½′.
$K = 8.070\mu$; a_1 is the 10th order.

Name	α °	′	n	λ	Name	α °	′	n	λ
H_γ	32	5	1,4398	0,434 μ	b_5	30	59	1,4267	1,466 μ
F	31	52	1,4372	0,485 "	a_6		55½	1,4260	1,613 "
D		36	1,4340	0,589 "	b_6		51	1,4250	1.792 "
C		29	1,4325	0,656 "	a_7		46	1,4240	2,019 "
a_1		19	1,4307	0,807 "	b_7		38	1,4224	2,303 "
b_1		17	1,4303	0,850 "	a_8		29	1,4205	2,689 "
a_2		14½	1,4299	0,896 "	b_8		13	1,4174	3,225 "
b_2		12	1,4294	0,950 "	a_9	29	46	1,4117	4,035 "
a_3		10	1,4290	1,009 "	c_1		29	1,408	4,62 "
b_3		8	1,4286	1,076 "	b_9		4	1,403	5,38 "
a_4		6	1.4281	1,152 "	c_2	28	30	1,396	6,46 "
b_4		4	1,4277	1,240 "	a_{10}	27	5	1,378	8,07 "
a_5		2	1,4272	1,345 "					

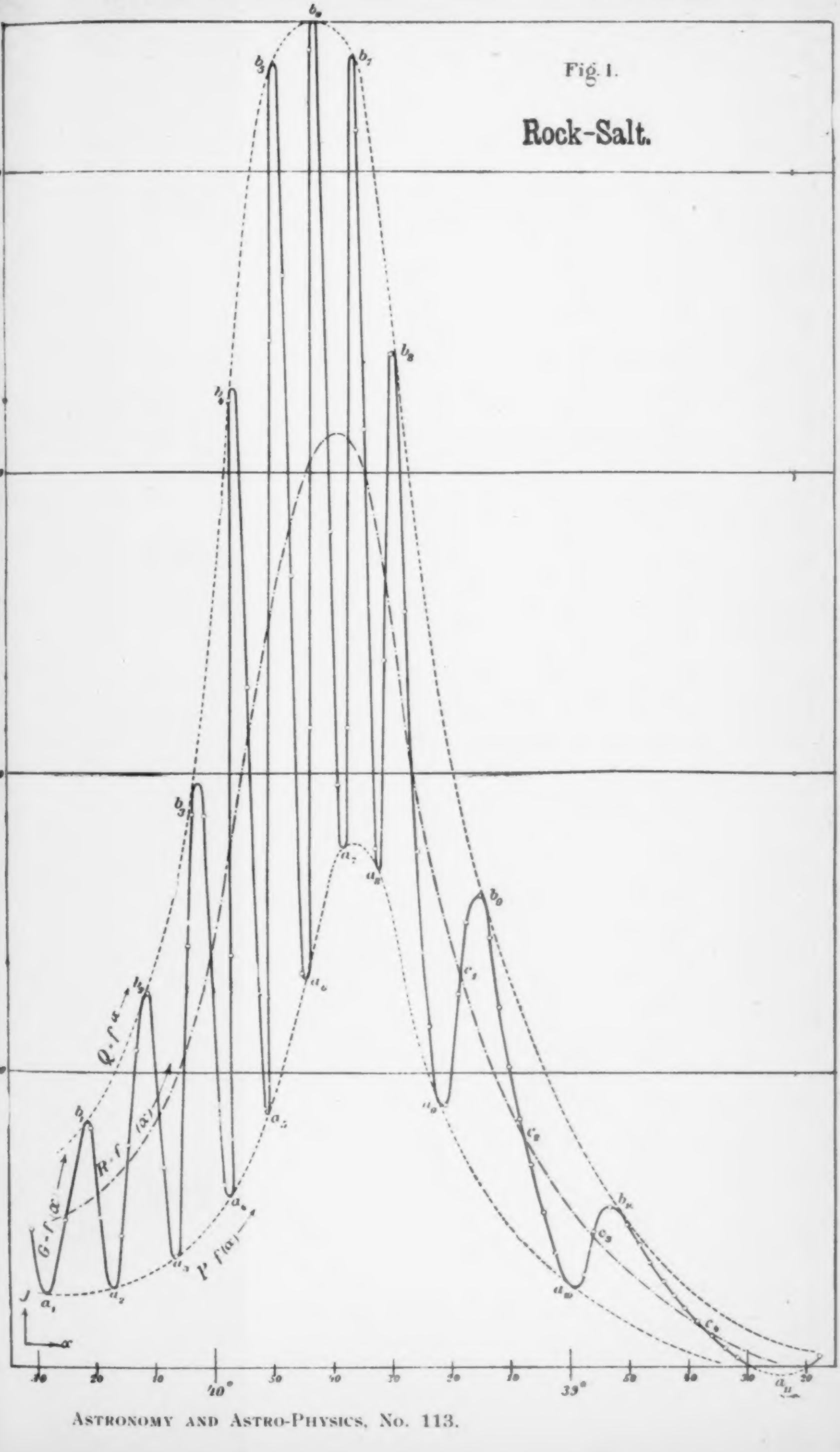


Fig. 1.
Rock-Salt.
800
600
400
200
Q·f(α)
R·f(α)
G·f(α)
P·f(α)
J
α
30
20
10
40°
30
40
30
20
10
39°
50
40
30
20

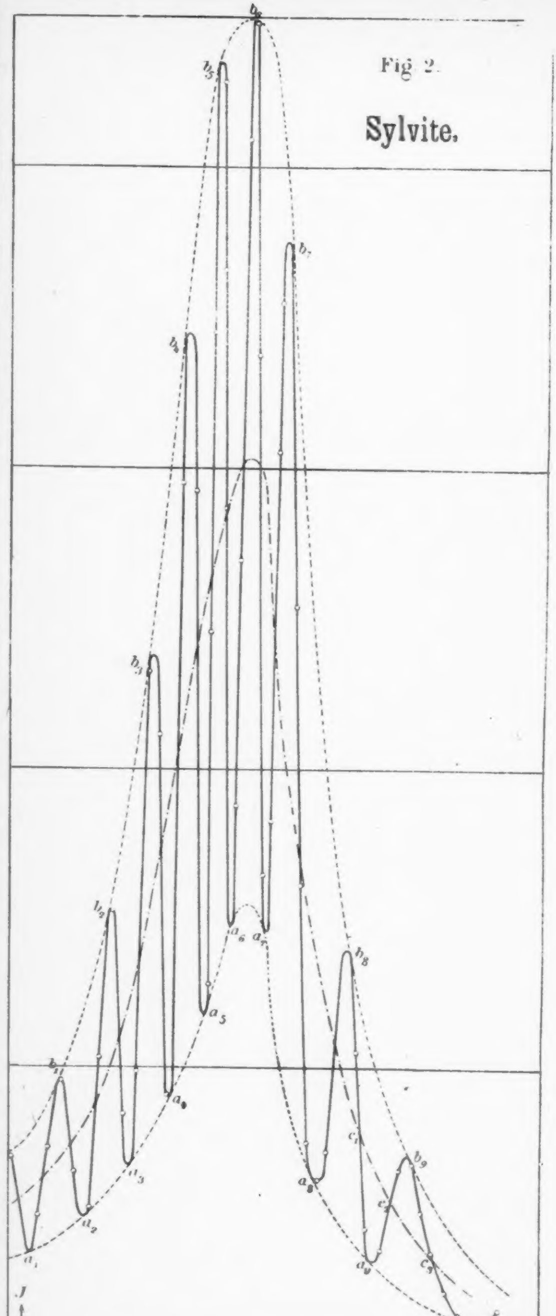


Fig 2.

Sylvite,

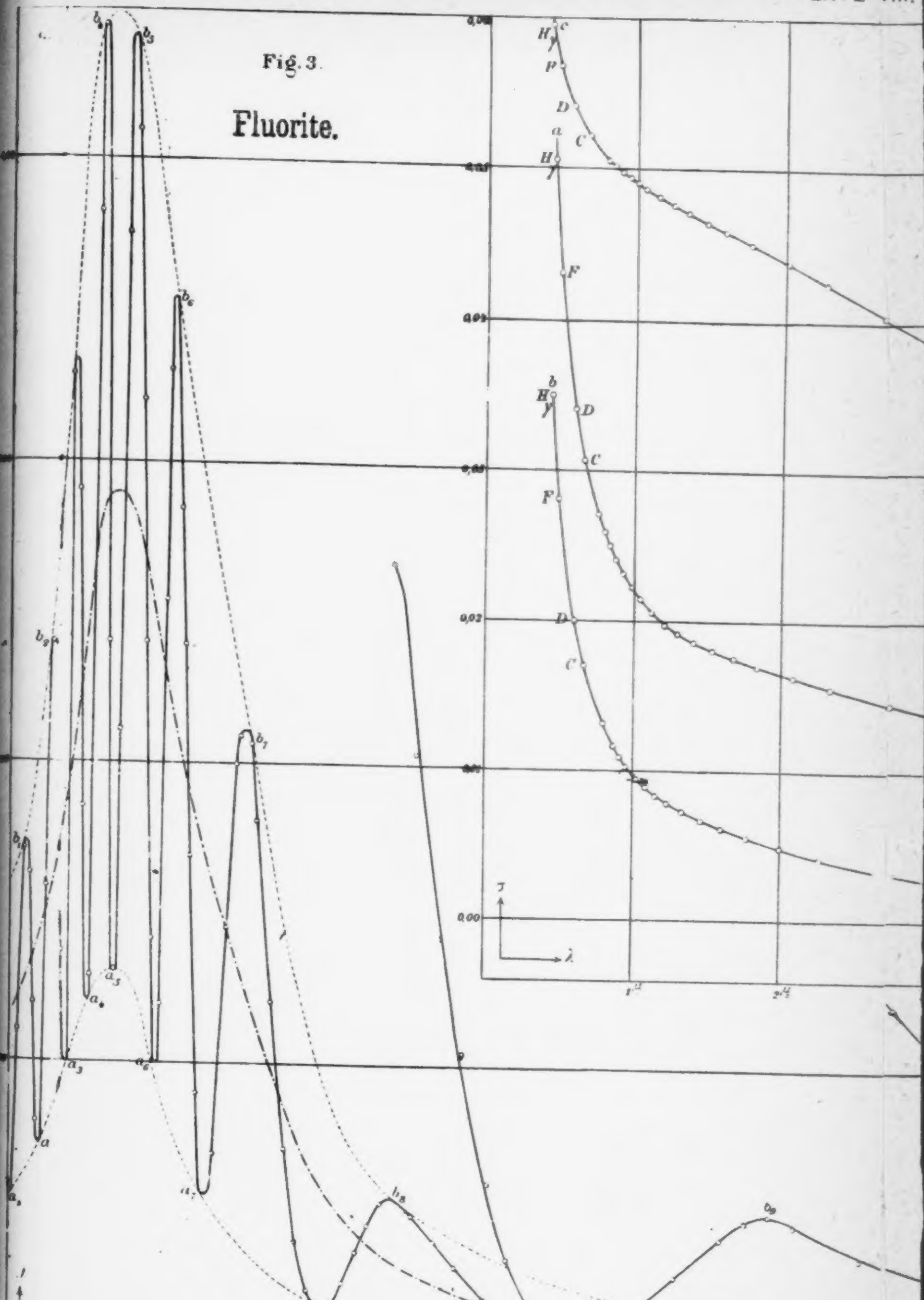
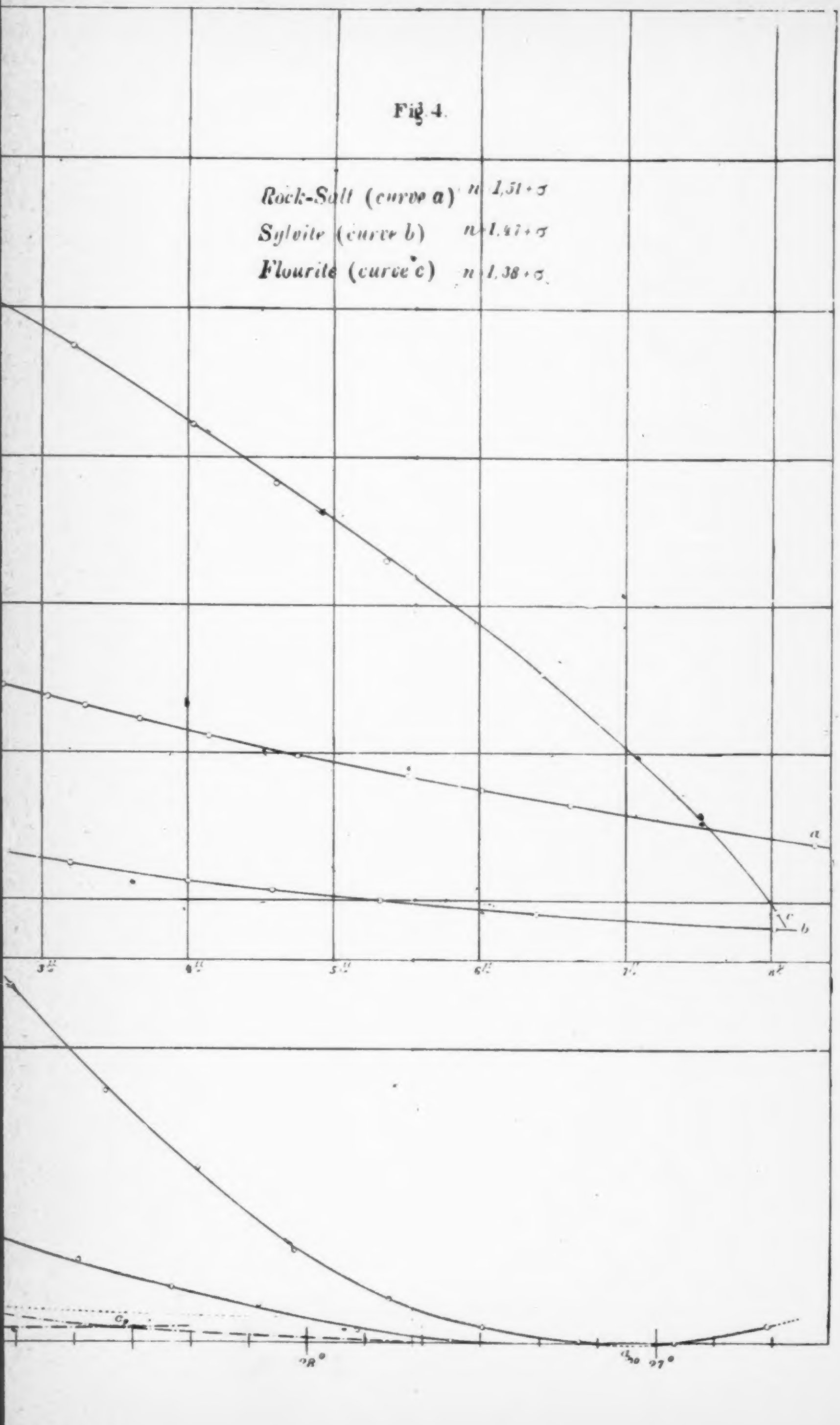


Fig. 3.
Fluorite.
0,00
0,02
1μ
2μ
31°
30°
29°

VIII.

Fig. 4.



Rock-Salt (curve a) n = 1,51 + σ
Sylvite (curve b) n = 1.47 + σ
Flourite (curve c) n = 1.38 + σ
a
b
c
28°
27°

The curve of dispersion shown in Fig. 4[c] exhibits more graphically than this table the peculiar character of the dispersion. From this it is seen that the dispersive power of fluorite decreases as far as $\lambda = 2\mu$ and then gradually increases reaching at $\lambda = 8\mu$ a value only slightly inferior to the value of the dispersion in the red.

Compared with rock-salt and sylvite, the dispersion of fluorite in the visible spectrum is exceedingly small, and unusually great in the infra-red, so that this material is peculiarly well adapted to the production of prismatic heat spectra, an advantage which is still further increased by the ease with which it can be worked and by the permanence of its surfaces in the air.

Physical Laboratory, University of Berlin,
June, 1892.

THE SPECTROHELIOGRAPH.*

GEORGE E. HALE.

The spectroheliograph is an instrument used in photographing the Sun by monochromatic light. It has been in daily use at the Kenwood Observatory for more than a year, and a collection of fifteen hundred photographs is sufficient evidence of its practical importance. Without entering into a discussion of these results, which have been described and illustrated in previous numbers of Astronomy and Astro-Physics, suffice it to say that the faculæ in the brightest part of the solar disc, as well as the chromosphere and prominences encircling the circumference, are clearly shown and sharply defined in the photographs.

The practicability of the instrument having thus been demonstrated, it may be of interest to examine its construction somewhat in detail, and to point out the advantages and disadvantages of such modifications of the original design as may seem best adapted for special purposes. Let us first consider, however, certain similar instruments, which, though never successfully employed, are nevertheless of interest and importance in the history of solar photography. These devices were brought to my attention not long after my independent invention of the spectroheliograph in 1889, and have been referred to in several of my papers. In order that the history of solar prominence photography may be complete, methods not embodying the principle of the spectroheliograph will also be described.

* Communicated by the author.

The first experiments in photographing the prominences were made by Professor C. A. Young in 1870. The following is his own account of the work: "The protuberances are so well seen through the F and 2796 (near G) lines that it is even possible to photograph them, though perhaps not satisfactorily with so small a telescope as the one at my command. Some experiments I have recently made show that the time of exposure, with ordinary portrait collodion, must be nearly four minutes, in order to produce images of a size which would correspond to a picture of the solar disc about two inches in diameter. . . Negatives have been made which show clearly the presence and general form of protuberances, but the definition of details is unsatisfactory. . . We worked through the hydrogen γ line, which, though very faint to the eye, was found to be decidedly superior to F in actinic power. The photographic apparatus employed consisted merely of a wooden tube, about 6 inches long, attached at one end to the eye-piece of the spectroscope, and at the other carrying a light frame. In this frame was placed a small plate-holder, containing for a sensitive-plate an ordinary microscope slide, 3 inches by 1."*

Professor Young has kindly shown me silver prints from the best original negatives. In these little more than the general outline of the prominence can be seen. This is due partly to a small displacement of the image during the exposure, as the polar axis of the telescope was slightly out of adjustment. The nebulous character of Hγ makes the employment of this line objectionable, but the serious difficulty lies in the use of a wide open slit. In observing prominences of ordinary size it is generally undesirable to open the slit sufficiently to allow the whole prominence to be seen at once, because the great increase in brilliancy of the continuous spectrum hides the details of structure. On account of their greater brightness, and the dark absorption bands in which they lie, the H and K lines are far superior to Hγ for prominence photography. A large number of photographs taken by myself in 1891 through the H and K lines by means of a wide slit, while in many cases showing the forms remarkably well, prove that this method is of little practical value.

Dr. Carl Braun devised in 1872 an apparatus for photographing the prominences through a narrow moving slit, and published a description of it in *Astronomische Nachrichten*, No. 1899; *Poggendorffs Annalen*, Bd. 148, S. 475, and also in the *Berichte von*

* *Nature*, Dec. 28, 1870. Reprinted from the *Journal of the Franklin Institute*.

dem Haynald'schen Observatorium zu Kalocsa. Upon a large metal plate fastened to the eye-end of an equatorial refractor a modified form of spectroscope is so arranged as to allow a limited motion of rotation, in a plane containing the axes of the collimator and observing telescope, about a pivot situated at the irpoint of intersection. The solar image formed by the equatorial is focussed on a slit at the end of the collimator. Passing out of the collimator the rays fall vertically upon a right-angled prism, which is so ground that for rays falling normally upon the second surface the limit of total reflection corresponds to the index of the prominence line employed (h or $H\gamma$). It is thus intended that all rays of greater refrangibility shall be totally reflected, and pass out of the apparatus to one side. The rays of less refrangibility than $H\gamma$ are refracted through the hypotenuse surface, and fall upon the similar surface of a second right-angled prism, which is exactly parallel to the first, and about 0.1 mm. from it. In passing out of this second prism the rays are rendered parallel to their original direction. They then meet a third prism of a slightly obtuse angle, by means of which all rays except those of a refrangibility very nearly equal to that of $H\gamma$ leave the optical system in a diverging bundle. $H\gamma$ with the rays near it are totally reflected, and after passing out of the prism they are brought to a focus by a small observing telescope, thus forming a nearly monochromatic image of the slit. A second slit near this focus cuts out the $H\gamma$ region, and a camera fastened upon the supporting plate enlarges the image 8 or 10 times. In photographing a prominence the clock-work of the equatorial is to keep the solar image motionless, while at the same time by a system of long levers the plate carrying collimator, prisms and telescope is made to turn slowly on the pivot, the stationary camera building up the prominence image upon the sensitive plate.

The idea of building up an image of a prominence by photographing the successive images of a moving slit was possibly suggested to Dr. Braun by the experiments of Professor Young and others in attempting to observe prominence forms with a rapidly oscillating narrow slit.* Zöllner's criticism of oscillating slits and rotating spectroscopes, based on experiments made in 1869 on terrestrial light-sources,† was substantiated by Professor Young's conclusion that a widely opened slit is best suited for visual observations, and the oscillating slit was never employed

* Described in *Nature* Dec. 28, 1870.
† *Astronomische Nachrichten*, No. 1772.

in practice. Dr. Braun seems to have been the first to see that the retina could be very advantageously replaced by the photographic plate.

A careful examination of his proposed apparatus reveals certain points of excellence and some defects. It is safe to say, however, that if it were constructed as described, and used with the Hγ or *h* line and the collodion plates then in vogue, it would not have proved of practical value.

It is indeed doubtful whether any form of apparatus in which either the Hγ or *h* line is employed could be successfully used in photographing the prominences. Images of some sort would probably be obtained, but they would be too feeble for practical purposes. Present success in solar prominence photography is largely due to our employment of the brilliant K line. As compared with K, Hγ and *h* are feeble lines. Almost equally serious is the fact that they lie on a background of bright atmospheric spectrum, while H and K are enclosed in broad dark absorption bands. In practice the second slit of a spectroheliograph cannot be made so narrow as to allow the passage of the prominence line alone. Some of the atmospheric spectrum on either side of the line is also admitted to the photographic plate, where it tends to obscure the image of the prominence. In the case of H and K the dark bands largely do away with this difficulty, as I pointed out in my studies of these lines in 1891. H cannot be used, however, on account of its close companion, the Hϵ line, and our choice is therefore narrowed down to K.

Dr. Braun's device for producing a monochromatic image of the slit is ingenious, but its entire practicability may be doubted. It would have to be constructed with great accuracy for light of a single wave-length, and its delicacy would interfere with permanency of adjustment. But even under the best of conditions it would hardly succeed in isolating a single line in the spectrum, as Dr. Braun himself remarks: "Man wird es wohl nicht dahin bringen können, dass durch diese Justirungen eine Spectrallinie (Hγ) vollständig isolirt werde; und es wird immer einiges Licht aus der Nachbarschaft dieser Linie auf die Platte gelangen. Doch das schadet nichts; denn die Folge davon ist nur die, dass auch die ganze Sonnenscheibe mit Flecken und Fackeln in einem Kräftigen Bild dargestellt werden wird."* It is true, however, that this additional light, while of advantage in the way pointed out, would make it difficult and perhaps impossible to photograph prominences, for which, it should be remembered, the instrument was primarily designed.

* *Berichte von dem Hayanldschen Observatorium*, 1886, p. 162.

The paragraph quoted above clearly proves that the idea of photographing the faculæ was a secondary one, and did not involve the belief that any advantage over ordinary methods of photography would result from the use of the Hγ line.

Another disadvantage of the apparatus is the loss of light when the axis of the collimator makes an angle with the axis of the equatorial. The maximum loss depends upon the diameter of the solar image. It can be obviated by increasing the angular aperture of the collimator.

A difficulty which cannot be avoided with Dr. Braun's apparatus also results from the motion of the slits in a circle. With a large solar image the maximum departure of the slit from the in focal plane of the equatorial would have a very appreciable effect distorting the image.

Further disadvantages are the weight of the moving parts, the method of producing the motion by means of the driving-clock of the equatorial, and the impracticability of constructing the instrument on a large scale.

The advantages of the apparatus are the equality of the angular motion of the two slits, and the consequent small distortion of the solar image.

Another form of the apparatus, in which it was proposed to isolate the Hγ line in the spectrum formed by two prisms, agreed in all other particulars with the device described above, but was considered by Dr. Braun to be much inferior. Its obvious disadvantage would be the curvature of the lines in the spectrum, and the resulting distortion of the solar image. Neither of the instruments was ever constructed. The projects were first made known tome by Dr. Braun* in reply to a published note on my proposed methods of photographing the prominences.†

In 1874 Dr. Oswald Lohse made several unsuccessful attempts to photograph the chromosphere and prominences by direct methods, *i. e.*, using the direct image of the Sun without a spectroscope. In 1880 he devised a special form of apparatus for the purpose. It consisted of a direct-vision spectroscope held within a large metallic drum, with its axis of collimation parallel to the axis of the telescope to which it was attached. The Sun's image at the focus of the equatorial was made to fall upon a metallic diaphragm exactly equal to it in size, and as the spectroscope was placed eccentrically in the drum, the radial slit received light from the region outside the diaphragm, including, of course, the chromosphere and prominences. The drum was supported in an

* *Astronomische Nachrichten*, No. 3014. † *Ibid*, No. 3006.

iron frame-work, and was rotated by hand, so that the slit passed over all points on the limb in one complete revolution. A second slit at the focus of the spectroscope allowed only the $H\gamma$ line to fall upon a stationary sensitive plate beyond it.*

Dr. Lohse's apparatus was thoroughly tested by a long series of experiments carried on at Potsdam, but it did not prove a success, and the investigation was finally abandoned.

The cause of failure lay not in the principle on which the apparatus was based, but in the means adopted to carry it into effect. The employment of the $H\gamma$ line was attended with the disadvantages mentioned above, and these were aggravated by the small dispersion and the illumination of the field by the direct vision prism. Add to these the obvious defects in the mechanical design of the instrument, and the impossibility of producing uniform rotation by hand, and it is easy to account for the lack of success.

In a paper published in 1872, Lockyer and Seabroke proposed to use a ring slit in the following manner for photographing the prominences: "A large Steinheil spectroscope is used, its usual slit being replaced by the ring one. A solar beam is thrown along the axis of the collimator by a heliostat, and the Sun's image is brought to a focus on the ring slit by a 3¾-inch object-glass, the solar image being made to fit the slit by a suitable lens. By this method the image of the chromosphere received on the photographic plate can be obtained of a convenient size, as a telescope of any dimensions may be used for focussing the parallel beam which passes through the prisms on to the plate."† Drawings were exhibited showing prominences observed with the ring slit, but I can find no record that photographs of the chromosphere and prominences were ever obtained in this way. The disadvantages of the method are evidently those of the ordinary open slit already referred to.

In 1879 a letter was published in the *Comptes rendus* describing a method designed by C. W. Zenger to photograph the chromosphere, prominences and corona without the use of a spectroscope. The plate was first put into a solution of pyrogallic acid and citrate of silver, and then given a very short exposure to the direct solar image, using "une couche absorbant tous les rayons dont est composée la lumière de la couronne et des protubérances solaires." The author goes on to add: "C'est en étudiant par le spectroscope des pellicules ainsi obtenues, que j'ai constaté l'ab-

* *Z. f. Instrumentenkande*, 1, 22.
† *Proceedings Royal Society*, v. 21, p. 105.

sorption de raies caractéristiques de la couronne et des protubérances, et c'est pourquoi les protubérances et la chromosphère, sur les épreuves négatives, apparaissent blanches; la couronne en est moins prononcée, seulement blanchâtre, ce qui montre que la lumière coronale est très-distincte de celles de la chromosphère et des protubérances."* Although M. Zenger declared his readiness to send specimens of his negatives to the Academy, the subject seems to have been dropped, and further details were not made known.

M. Janssen has also tried to use the direct solar image. In a short note on the subject he says: "Il faut que l'action lumineuse solaire s'exerce assez longtemps pour que l'image solaire devienne positive jusqu'aux bords, sans les dépasser. Alors la chromosphère se présente sous forme d'un cercle noir, dont l'épaisseur correspond à 8″ on 10″."† In this case, and also in Zenger's, where a direct image of the Sun is received upon a photographic plate, it is highly improbable that the chromosphere or prominences produce any appreciable effect. The "black circle" is solely due to the photographic action of the brilliant disc of the Sun, and would be formed even if the chromosphere did not exist.‡

Two methods of photographing the chromosphere and prominences were independently devised by the writer in 1889.

(1.) The rate of the driving clock of an equatorial telescope is so altered that the Sun's image moves slowly across the slit of a spectroscope of considerable dispersive power, the direction of the Sun's motion being at right angles to the slit. One of the prominence lines is brought into the center of the field of the observing telescope, where it passes through a narrow slit just within the focus, and falls upon a photographic plate. The plate is moved at right angles to the spectral lines at a velocity depending upon that of the Sun's image.

(2.) The solar image is kept stationary by the driving clock of the equatorial, and the slit of an attached spectroscope of considerable dispersive power is given a uniform motion across the axis of the collimator. Before the stationary photographic plate at the focus of the observing telescope a second slit moves at such a velocity that a given prominence line constantly falls upon the plate.§

* *Comptes rendus*, t. 88, p. 374.

† *Comptes rendus*, t. 91, p. 12.

‡ See note by Abney, Schellen's *Spectrum Analysis*, 2d English Edition, p. 372.

§ *Technology Quarterly*, November, 1890; *Astronomische Nachrichten*, No. 3006.

My experiments in solar prominence photography made at the Harvard Observatory during the winter of 1889-90 were restricted to the first of the above methods. The mirror of the horizontal telescope employed was so greatly distorted by the Sun's heat that it was never even possible to see the prominences well, and photography under such conditions was quite out of the question. The means used to move the photographic plate at the focus of the large diffraction spectroscope were moreover inadequate, and no valuable results were obtained. Knowing nothing at that time of the exceptional advantages offered by the K line, and convinced that Hγ and *h* were by no means suited for the work, I lost much time in a search for a photographic plate sufficiently sensitive to the less refrangible rays, in the hope that the C line, which serves so well in visual work, might also be employed for photography. But although many experiments were made with cyanin, alizarin blue and other dyes, the high degree of sensitiveness desired was never attained. In the spring of 1890 it became clear that further attempts with the horizontal telescope would be useless, and the work at Cambridge was discontinued.

In the autumn of 1890 a 12-inch equatorial refractor was ordered for the Kenwood Observatory, and in March, 1891, it was ready for use. This telescope, together with the large spectroscope permanently attached to it, has been already described.* Attention was first directed to the ultra-violet spectrum of the prominences, and the great brilliancy of the H and K lines in the photographs at once removed all difficulty in the choice of a suitable line for further attempts at photographing prominence forms. The constant presence of these lines, their sharpness and brilliancy, their suitability for photographic study with ordinary plates, and the peculiar advantages afforded by the dark bands in which they lie, left no room for doubt, and K was selected as the line to be used in future work. Incidentally the ultra-violet spectrum of the prominences was investigated, and the small number of lines at first found has now been increased to seventy-four.†

In the early experiments at the Harvard Observatory the photographic plate was carried at the focus of the observing telescope in a plate-holder sliding on *V*-shaped guides. This arrange-

* *Sidereal Messenger*, 1891, p. 321. This spectroscope has been used in all of my photographic work on the prominences and faculæ. The observing telescope and collimator are each of 3¼ in. aperture and 42½ in. focus, and the 4 in. Rowland grating has 14438 lines to the inch.

* The Ultra-Violet Spectrum of the Solar Prominences, *Sidereal Messenger*, *June* 1891; *Am. Jour. Sci.*, Aug. 1891; ASTRONOMY AND ASTRO-PHYSICS, vol. 11 (1892), pp. 50, 602, 618, 821.

ment was afterwards replaced by a small cylinder, mounted in a brass box with its axis parallel to the lines in the spectrum. A sheet of photographic celluloid film was wrapped around the cylinder, which was rotated with the film almost touching the second slit. By setting the grating at the proper angle the K line was made to pass through the second slit on to the sensitive surface at the focus. The K line (fourth order) being invisible, settings were made by calculating the wave-length it would have in the overlapping spectrum of the third order, and bringing this place into position by observing the spectrum through the second slit with a positive eye-piece.

Photographs showing the rough outlines of prominences were soon obtained, but they were much inferior to those taken through K with a simple wide slit. This was due to several causes, of which two were prominent: (1) The clepsydra used to rotate the cylinder was much too small (1 in. bore, 3 in. stroke), and the resulting motion of the film was not sufficiently regular; (2) It is practically impossible to adjust the motion of the film so nicely that it exactly equals that of the solar image.

This latter is a serious defect of my first method of prominence photography, and cannot be entirely removed in even a much more perfect form of the apparatus than that described above, on account of the variations in the apparent motion of the Sun. It is thus almost impossible to prevent distortion of the image, and this distortion is more likely to be a variable than a constant quantity. Another difficulty lies in the fact that the motion of the solar image must be exactly at right angles to the slit. When experience had emphasized these defects I decided to direct my attention to the development of the second method. Accordingly I devised a new form of clepsydra and a system of moving slits in June, 1891, to be adapted to the spectroscope used in all the previous work. The instrument was completed by Mr. Brashear in January, 1892.

Meanwhile I devoted considerable time to a study of the possibilities of the wide slit method, and obtained a large number of fairly good photographs of prominence forms in this way. The H and K lines in the fourth order spectrum were brought into the field, and the slit made tangent to the Sun's image at a point where observations through the C line had shown a prominence to be. With the most sensitive plates employed (Seed 26 x) the exposure was less than a second. As was to be expected, the sharpest photographs were obtained with the shortest possible exposure. The prominences were shown on the same plate in

both the H and K lines. The images in the latter line were stronger and sharper than those in H, on account of the greater brightness of K, and the superposition on H of the image due to the adjacent hydrogen ε line. In rare cases the line hydrogen α_1 was bright enough to give a faint image of the prominence. But although they are by far the brightest lines in the prominence spectrum the images in H and K with a wide slit would be comparatively faint were it not for the protection afforded by the broad absorption bands. These allow the slit to be widely opened without much increase in the brilliancy of the background.

It has been already mentioned that photographs of prominence forms taken with a wide slit are of no great practical value. It is true that under good conditions reasonably good pictures can be obtained of single prominences,* but the least whiteness of the sky greatly impairs the result. It is evidently important in this class of work to use a spectroscope with very long collimator (of course retaining the proper ratio of aperture to focus), in order that a wide slit may be used. The method is restricted by the fact that prominences of exceptional height cannot be photographed on account of the necessity of limiting the width of the slit.

In a paper presented to the Académie des Sciences in August, 1891, M. H. Deslandres describes some experiments made at the Paris Observatory in photographing the ultra-violet spectrum of the prominences, which confirm my earlier work. M. Deslandres had made no photographs of the *forms* of prominences, but suggested a method of doing so in the following words:

"M. Hale, qui, depuis longtemps, s'occupe de cette dernière question, a proposé plusieurs systèmes fort ingénieux, avec une fente étroite; mais ces systèmes ne s'appliquent qu' à une protubérance isolée, et non au pourtour entier du Soleil; de plus, ils ne donnent pas les vitesses. Je me suis arrêté à un dispositif tout différent, qui est le suivant:

"Le spectroscope, qui peut être quelconque, tourne tout d'une pièce autour d'un axe passant par le centre de l'image solaire et prolongeant l'axe optique de l'objectif. Le milieu de la fente est sur le bord solaire dont il rencontre successivement tous les points par la rotation de l'appareil. Devant la plaque photographique, on place une fente fixe qui correspond à la raie K du calcium. De plus, la plaque est mobile, de manière que, à un deplacement du milieu de la fente, corresponde un déplacement égal de la plaque. Ce résultat est assuré par de simples engrenages. Si donc le spectroscope tourne d'une manière continue avec une vitesse convenable, on obtient, sur la plaque, une bande de longueur égale à la circonférence du Soleil, qui donne toutes les protubérances avec leur forme exacte.

* One of these has been reproduced in my paper "Recent Results in Solar Prominence Photography," ASTRONOMY AND ASTRO-PHYSICS, January, 1891.

Mais la vitesse des protubérances n'est pas donné par ce procédé. Aussi convient-il de donner à l'appareil une serie de rotations rapides, separées par des poses de deux secondes, de manière à avoir sur la plaque, par example, 200 sections équidistantes de la chromosphère sur tout le pourtour solaire. Chaque section demandant environ trois secondes, on peut avoir l'ensemble en dix minutes. Si, d'ailleurs, on replace la plaque par un papier sensible enroulé sur des cylindres, et si le mouvement du spectroscope est rendu automatique, on obtient un appareil simple qui enregistre d'une manière continue la forme et la vitesse des masses incandescentes à la surface du Soleil."*

M. Deslandres' criticisms of my method are evidently inexact, for the prominences around the entire circumference of the Sun are well shown in a single photograph, and the velocities both in the line of sight and normal to it are respectively obtained by photographs of the distorted H and K lines and by a series of photographs of prominence forms taken at known intervals of time.

M. Deslandres' proposed apparatus has never been constructed, and he has hitherto obtained no photographs of the forms of prominences or faculæ. The proposed instrument is like that already described as having been devised by Dr. Lohse, and employed unsuccessfully in his experiments at Potsdam. The only change suggested is the motion of the plate across the second slit, giving the chromosphere in a straight line instead of in a circle. To anyone familiarized by experience with the necessity of avoiding complication in the apparatus, this proposed addition would be regarded rather as a defect than an improvement. Any slight variation in the motion of the plate would cause a distortion of the image, as already referred to in an enumeration of the disadvantages of my first method. M. Deslandres' apparatus has the same good and bad points as Dr. Lohse's rotating spectroscope, except in the important advantage arising from the use of the K line.

The first experiments with my improved apparatus in January, 1892, completely justified my anticipations of success. Not only was the entire chromosphere obtained in a single operation, but, with a shorter exposure, and the diaphragm between the slit and solar image removed, the faculæ in even the brightest parts of the disc were readily photographed. Plates taken with a double exposure showed the disc of the Sun with the faculæ and spots, and the encircling ring of chromosphere and prominences. Once adjusted the spectroheliograph proved to be simple and convenient in operation, and it has ever since been in constant use.

* *Comptes rendus,* 17 Août 1891.

In order to discuss intelligibly the advantages and disadvantages of this form of spectroheliograph it will be necessary to briefly describe its mode of construction. The essential parts are two movable slits, one at the focus of the collimator of a large grating spectroscope, and the other just within the focus of the observing telescope. The slits are about $3\frac{1}{4}$ inches in length, and adjustable in width. They are attached to carriages mounted on steel balls, so that they may be moved with perfect freedom across the axes of the tubes, in the direction of the length of the spectrum. A photographic plate-holder is supported just beyond the second slit, and, after drawing the slide, the plate-holder can be pushed forward by means of a cam until the surface of the plate almost touches the jaws of the slit. A small 90° reflection prism is attached to the slit carriage on the side toward the grating, and by a suitable combination of lenses a small portion of the spectrum can be viewed without disturbing the plate holder. This has not been used in practice, the K line being brought on to the slit by observing it directly with a low-power positive eye-piece. The motive power is supplied by a specially designed cepsydra, which is mounted within the braced frame of the spectroscope. It consists of a brass cylinder of 3 inches bore and 6 inches stroke, supplied with two inlet and two outlet valves, and a very accurately made micrometer gate-valve. The piston has a cup-shaped leather packing, and the phosphor-bronze piston-rod passes through a stuffing-box in the upper head. At the end of the rod a system of bell-crank levers is attached, and these convey the motion to the slit at the focus of the observing telescope. An extension of the piston-rod passes through a guide in the upper frame of the spectroscope, and connects with the first slit by another lever system. It will be seen that when the piston is set in motion, the two slits will move simultaneously, and in opposite directions. The collimator and observing telescope are inclined to each other at an angle of 25° ; they are exactly alike in aperture ($3\frac{1}{4}$ inches) and focal length ($42\frac{1}{2}$ inches). A 4-inch Rowland grating with 14438 lines to the inch stands at the point of intersection of their axes.*

The obvious advantage of this form of spectroheliograph over others previously described is in the small weight of the moving parts, and the ease with which it can be constructed from an ordinary solar spectroscope. But while successfully accomplishing the work for which it is intended, the instrument has one impor-

* A fuller description of this instrument is given in ASTRONOMY AND ASTRO-PHYSICS, May, 1892, p. 407.

tant disadvantage. I refer to the distortion of the image resulting from the motion of the slits.

In the equation for the plane reflection grating

$$\lambda = \frac{d}{n}(\sin \theta \pm \sin \omega)$$

θ = angle of diffraction,
ω = angle of incidence,
λ = wave-length of line observed,
n = order of spectrum employed,
d = distance between adjacent lines of grating.

Then

$$\sin \theta = \frac{n\lambda}{d} \pm \text{F} \sin \omega.$$

Differentiating, we have

$$d\theta = \frac{\cos \omega \, d\omega}{\cos \theta}, \tag{1}$$

$\frac{n\lambda}{d}$ being a constant for a given line.*

In the case of the Kenwood Observatory spectroheliograph, when used in photographing an image of the Sun 51 mm. in diameter, we have

$$\begin{aligned} \theta \text{ (maximum)} &= 14^\circ\ 36' \\ \theta \text{ (minimum)} &= 13^\circ\ 42' \\ \omega \text{ (maximum)} &= 40^\circ\ 54' \\ \omega \text{ (minimum)} &= 38^\circ\ 42' \\ d\omega &= 51 \text{ mm.} \end{aligned}$$

Substituting in (1), we find

$$d\theta = 39.8 \text{ mm.}$$

That is, the diameter of the photographed solar image which is parallel to the length of the spectrum will be reduced by the distortion from 51 mm to 39.8 mm. The diameter parallel to the lines of the spectrum will of course remain undistorted.

This result, however, is only an approximate one, for the distortion for equal values of $d\omega$ increases from one side of the image to the other.

Thus if we make $d\omega = 1$ mm, and calculate the values of $d\theta$ for one side, the center and the other side of the solar image, we obtain the respective values

$$\begin{aligned} d\theta &= 0.78 \text{ mm (for maximum value of } \theta) \\ &= 0.79 \text{ mm (for mean value of } \theta) \\ &= 0.80 \text{ mm (for minimum value of } \theta). \end{aligned}$$

* See Young, *Amer. Jour. Sci.*, November, 1880.

In measuring photographs distorted in this way the necessary correction for a point at a given distance from the Sun's limb may be taken from a table of corrections, which is readily constructed for a given position of the Sun's image with respect to the axis of the collimator. In work with this form of spectroheliograph it is therefore desirable to provide means for placing the solar image exactly in the center of the collimator. It is also convenient to orient the image so that the distorted axis shall be parallel to the solar equator in the photograph. For this purpose the whole instrument can be rotated about the axis of the collimator, the direction of the slit being read off on a position circle. The parallel lines on the photographs, which are due to dust on the slit, and cannot be altogether avoided in any form of spectroheliograph when the slit is narrow, are made to serve a useful purpose in the orientation of the image.

The distortion just mentioned might be compensated by introducing a cam to move the photographic plate, the form of the cam being calculated from the equation given. Undistorted copies can be made from distorted photographs by means of a simple device of the writer's. The distorted photograph is projected by a suitable lens on to a screen, in which there is a slit parallel to the long axis of the image, and exceeding it in length. Just beyond the screen, and supported in a light frame of brass tubing in the focal plane of the lens, is the photographic plate. The screen and frame are so connected that while the slit moves across the short diameter of the image, thus giving the exposure, the plate moves in the opposite direction a distance equal to the difference between the long and short diameters of the image. A cam calculated from equation (1) secures the proper ratio of the two motions. Thus circular images of any desired size are obtained.

There remains to be mentioned another source of distortion, which has a slight but still appreciable effect on the photographed image—the curvature of the lines of the spectrum. Were prisms employed the curvature would be pronounced, and the distortion serious. With gratings the curvature is very slight. With the solar image central, and the slit parallel to the Sun's axis, the distortion at any point due to curvature of the lines is evidently a function of the heliocentric latitude, and may be so tabulated. The second slit of a spectroheliograph should have the same curvature as the K line.

The ratio of aperture to focal length in the collimator of a spectroheliograph, is not, as in a spectroscope, equal to the ratio of

aperture to focal length in the equatorial to which it is attached. The collimator objective must have a larger angular aperture, in order that light from the edge of the Sun's disc may not be lost when the slit is in its extreme positions. The same holds true even if the slit is fixed in the axis of the collimator, for without large angular aperture light from the upper and lower portions of the image would be lost.

Let

F = focal length of equatorial (inches),
A = aperture of equatorial,
f = focal length of collimator,
d = diameter of solar image at focus of equatorial,
a = required aperture of collimator.

Then,
$$a = \frac{5d}{4} + \frac{Af}{F}$$

With this aperture no light will be lost up to a distance of about 4′ from the Sun's limb. Prominences of greater height are exceptional, and can be photographed singly in the center of the field. It will be seen that these conditions are not met in the Kenwood Observatory spectroheliograph, as this instrument was primarily intended for a solar spectroscope. The chromosphere and prominences are therefore photographed at a disadvantage, and the contrast in brilliancy between the limb and center of the solar disc is abnormally great in the negatives.

The effect of motion in the line of sight must now be considered The slight displacement of the K line due to the axial rotation of the Sun is altogether inappreciable, and may be neglected. Eruptive prominences, on the other hand, offer difficulties both to the spectroscope and the spectroheliograph. When the motion in the line of sight is large, and unequal in different parts of the same prominence, neither instrument will allow the true form to be distinguished. In the case of a wide-slit observation with the spectroscope rapid motion in the line of sight will cause the portions involved to be displaced from their normal positions in the image. As a result the form of the prominence will be distorted, unless every part of the prominence has the same radial velocity at the same time. In this exceptional case the entire prominence form would be displaced in the spectrum, but not distorted. In the spectroheliograph, or in any instrument for photographing prominences through a narrow slit, the effect of motion in the line of sight would be the same as in the case of the spectroscope, until the displacement became so great as to throw the K line en-

tirely outside of the second slit. The portion of the prominence moving with sufficient radial velocity to produce so large a displacement would not appear in the photograph. As the second slit is rather wide in practice difficulties of this sort are rare.

The images of Sun-spots in photographs of the solar disc taken with the spectroheliograph depend as to their sharpness on several conditions. Most important of these is the width of the slits. With the width necessary for faculæ and prominences it is clear that the spots must be very poorly defined. Other conditions which conspire to bring about the same result are the superposition of faculæ on the spot-penumbra, and the comparatively long exposure required.

In a modified form of the Kenwood Observatory spectroheliograph which I have designed for the 40-inch equatorial of the Yerkes Observatory a single objective or a concave mirror will serve for both collimator and observing telescope, the second slit being placed immediately below the first slit. The slit-carriages will be connected with each other and with the clepsydra by an adjustable fork, thus allowing the proper relative motion to be obtained. It will be seen from equation (1) that the distortion of the image will be very small in this special case. Precautions will be taken to obviate difficulties arising from the diffuse light and the rather imited field peculiar to this form of the instrument.

I have also devised an automatic spectroheliograph to be used with a large heliostat and an objective giving a three-inch image of the Sun. Photographs taken with this instrument will be free from all distortion, except the very slight amount due to the curvature of the lines in the grating spectrum, and this may readily be allowed for. A rigid frame is carried on wheels of large diameter, running on ball bearings. The tracks on which the wheels rest are parts of a single casting, and are placed truly parallel; the heavy casting is bolted to a stone pier, the tracks having first been placed horizontal and at right angles to the meridian. The carriage can thus be moved several inches on the tracks in an east or west direction, a clepsydra furnishing the motive power. Attached to the carriages are two telescopes with their axes parallel. They are exactly alike in focal length (about three feet) and aperture, the latter being calculated by the expression given above. Each telescope has a vertical fixed slit in its axis at the focus of the objective. One of the telescopes serves as a collimator, and a plane Rowland grating standing on the carriage receives parallel rays from it. The length of the

lines on this grating is equal to the aperture of the collimator. The width of the ruled surface is equal to the projection on the grating of the horizontal width of the illuminated portion of the collimating objective, the grating being set at the proper angle for use. The spectrum is thrown upon a plane silvered-glass mirror, fixed at an angle of 45° with the axis of the second telescope, and is thence reflected to the second slit. The K line passes through the slit and falls upon a sensitive plate.

The operation of the instrument is simple. The Sun's image having been formed by the large objective, and the K line set on the second slit, it is only necessary to place the photographic plate in position, and open the valve of the clepsydra. The first slit then passes over the solar disc, and the photograph is secured. The adjustments remaining the same, the second photograph is obtained on the back stroke, and so on indefinitely. The valve of the clepsydra, and the apparatus serving to change the plates are controlled by electricity. The former is a four-way valve, and takes the place of the five valves used on the clepsydra of the present Kenwood Observatory spectroheliograph. The plate-changing apparatus consists simply of a wheel about four feet in diameter, with its plane in the focal plane of the spectroheliograph. Three dozen sensitive plates (4 × 5 inches) are carried in clamps on the circumference of the wheel. A simple device controlled by an astronomical clock operates the clepsydra valve and moves the wheel through $\frac{1}{36}$ of its circumference at the proper time intervals. Thus photographs of the Sun can be taken automatically with any desired frequency.

This automatic spectroheliograph has not yet been constructed. It is possible that it may be found desirable to substitute a single objective for the two objectives and plane mirror of the original design. The freedom of the image from distortion and the comparatively small number of lines required on the grating are important advantages of this type of spectroheliograph; it is evidently unsuitable for use on an equatorial, but mounted on a solid pier in a dark room, it will evidently prove serviceable when employed with a good heliostat.*

KENWOOD OBSERVATORY, University of Chicago.

Feb. 14, 1893.

* There remains to be described a form of spectroheliograph in which a single concave mirror replaces the two objectives ordinarily used. This arrangement has been adopted in my apparatus for photographing the corona without an eclipse. Should the experiments shortly to be undertaken with it prove successful, the instrument will be discussed in a future paper in connection with certain considerations involved in thus photographing an object giving a continuous spectrum.

RESEARCHES ON THE SPECTRUM OF β LYRÆ.*

A. BELOPOLSKY.

The researches on the spectrum of β Lyræ which I have made with the new spectrograph and the 30-inch refractor of the Pulkowa Observatory by means of orthochromatic plates, relate chiefly to the region between H_β and D_3.

The seventeen photographs show the following:

The dark and bright lines are present. The dark lines are especially numerous, delicate and distinct in the region between H_γ and H_β. Another kind of dark lines which particularly characterizes the spectrum, is broader than the first and very distinct, with bright edges which can sometimes be regarded as independent bright lines. The D_3 line is bright. The continuous spectrum becomes at times very weak.

Especially to be mentioned is the line at λ 5014. While the others disappear at times this line is always present, but its bright edges become weak and even entirely vanish (Sept. 24).

The F and D_3 lines must be specially investigated.

The former is generally seen double (Aug. 30 to Oct. 3 inclusive). The brightness and breadth of the components vary. Sometimes both are equal and between them is a narrow dark line; now the one is broader than the other, or the reverse; now one of them disappears, and in its place appears a rather broad dark line; now both are seen as bright lines, and on one side is a broad dark line. If we represent by *R* that one of these lines which is displaced toward the red, as compared with the hydrogen spectrum, and by *V* the other line, we find the following differences of wavelength between them and the F line of the comparison spectrum; *DR* and *DV* represent the dark lines.

1892	*R* Tenth-metres	*V* Tenth-metres	*DV* Tenth-metr's	*DR*
Sept. 7	—	2.94 diffuse	—	1.00 weak
8	3.25 distinct	3.63 distinct	—	7.53 broad, distinct
18	2.54 distinct	3.72 weak	0.03	—
19	3.39 distinct	—	—	—
20	2.21 weak	3.43 distinct	0.16	—
23	1.96 bright	2.99 diffuse	0.35	—
24	1.73 bright, narrow	3.41 diffuse	0.94	—
25	2.44 distinct, sharp	—	—	—
27	2.37 distinct, broad	—	2.51 broad	—
30	3.01 broad	2.29 narrow	0.38	—
Oct. 2	2.65 broad	3.23 broad	0.24	—
3	3.79 broad	3.06 broad	0.08	—

* Translated from *A. N.*, 3129.

The probable error of each of these numbers is ± 0.20 tenth-meters.

The D_3 line, as has long been known, disappears from time to time and this is also shown by my photographs; but beside this it is double. I cannot decide whether a dark line appears between the components, as the continuous spectrum is quite weak even at λ 5750, and the D_3 line stands quite isolated.

It is double on the 4th and 30th September, and particularly sharp on the very good plate of Sept. 30. The difference of wave-length on this day is 8.2 tenth-meters.

Other aspects of the line are as follows:

Aug.	24	very bright, single.	Sept.	23	missing; plate good.
	25	very bright, single.		24	very weak; plate good.
	30	missing; plate fogged.		25	only traces; plate weak.
Sept.	4	distinct, double.		27	very weak.
	7	distinct, single.		30	very bright, double.
	8	very narrow, single.	Oct.	1	very weak; plate weak.
	18	perhaps traces.		2	distinct, single.
	19	very weak.		3	weak; plate good.
	22	invisible; plate weak.			

As for the other lines, I shall reserve a detailed description until I possess more abundant photographic data; I shall here give only provisional wave-lengths obtained from the measurement of a single plate. They are as follows:

5876.2 bright	*5170.3* dark	4651.8 dark
5864.2 dark	5162.9 "	4633.4 "
5703.3 bright edges	5150.1 "	*4622.2* "
5600.0 dark	5056.1 "	*4583.0* "
5464.0 bright	5017.7 bright edge	4575.3 "
5433.1 dark	*5014.3* dark, bright edges	4564.6 "
5429.7 "	5005.4	4557.1 "
5386.3 "	4964.2 dark, bright edges	4553.3 "
5380.2 "	*4922.7* " "	4547.5 "
5316.2 "	F	4531.7 "
5272.1 "	4821.8 dark	4529.0 "
5234.8 "	4736.2 "	4512.9 "
5230.5 bright	4714.3 "	4509.9 "
5223.4 "	*4706.9* "	4506.6 "
5207.6 dark	4701.6 "	*4481.3* bright edges
5190.9 "		

The wave-lengths printed in italics belong to the sharpest lines.

The explanation of the most interesting phenomenon must be deferred. It seems that a dark line in the region of F moves to and fro, and modifies the appearance of a bright one. The double D_3 line apparently indicates a close double star; period 26 days?

I must also mention that no traces of D_3 are to be seen on three photographs of the spectrum of γ Cassiopeiæ.

PHOTOGRAPHY OF THE SOLAR CORONA WITHOUT AN ECLIPSE.*

GEORGE E. HALE.

In a recent number of the *Comptes rendus*† M. Deslandres describes some attempts made at the Paris Observatory to photograph the solar corona without an eclipse. Two exactly similar prisms are placed with their faces parallel, and the base of one opposite the refracting edge of the other, as in Newton's classic experiment on the recomposition of light. Instead of being placed very close together, however, the prisms are separated by a considerable distance, so that the second prism receives only a portion of the spectrum formed by the first. Sunlight being employed, and the recomposed light on its emersion from the second prism falling on a lens or mirror, a colored image of the Sun is obtained. If one of the prisms is displaced perpendicularly to the line joining the two, all the colors of the spectrum enter successively into the formation of the image. The idea is to photograph the surroundings of the image with light of various colors, in the hope of finding that at some region of the spectrum the light of the corona is so much brighter than the diffuse light of the sky that photographs of the form of the corona can be obtained without an eclipse. On certain of M. Deslandres' plates, especially those for which ultra-violet light was used, corona-like forms appear around the solar image; but that they truly represent the corona, and do not result from instrumental or photographic defects, has yet to be established, as M. Deslandres himself points out.

At a meeting of the Section of Mathematics and Astronomy of the Chicago Academy of Sciences on Dec. 6, 1892, I described in detail a method of photographing the corona without an eclipse, devised by myself in April, 1892, which is based on exactly the same principle. I proposed to isolate light of any desired wavelength by means of a spectroheliograph, and thus to photograph the sky surrounding the Sun, employing such a region of the spectrum as experiment proved to be best adapted to show the corona on the background of the sky. Professor Vogel's measures of the absorption of the solar atmosphere at the center and edge of the disc show that the absorption increases more rapidly for short than for long waves. In his experiments on photographing the corona without an eclipse Dr. Huggins recognized

* Communicated by the author.

† *Comptes rendus*, Jan. 23, 1893.

this fact, and endeavored to restrict photographic action to the blue rays of the spectrum by the use of colored glass screens, and specially prepared plates. Results obtained in this way, while not demonstrating with certainty that the photographs truly represent the corona, were more encouraging than those secured with absorbing media of other colors.* In my own consideration of the subject I was led by Professor Vogel's measures to believe that, within certain limits, the brightness of the corona with respect to the surrounding sky is inversely proportional to the wave-length of the light employed for the observation. It would thus seem desirable to employ ultra-violet light in future photographic experiments.

In May and June, 1892, I attempted to photograph the corona with the spectroheliograph of the Kenwood Observatory. The first slit was made rather wide and the grating set at such an angle as to bring a portion of the ultra-violet of the first order spectrum on to the second slit. The direct light of the Sun was prevented from entering the spectroheliograph by means of a diaphragm somewhat larger in diameter than the solar image. Photographs were obtained which resembled the corona, but I greatly doubted whether the images were not of instrumental origin, or due to haze or passing clouds. Appreciating the importance of the question, I decided to construct an instrument for the express purpose of photographing the corona. The work was undertaken in August, but on account of various delays it has not yet been completed. The apparatus will be carried on a small equatorial mounting. A silvered glass concave mirror of 6½-inches aperture and 50 inches focus, made for this purpose by Mr. Brashear in September, forms an image of the Sun on a diaphragm, which excludes all of the direct light of the disc from the spectroheliograph. The latter is similar to the spectroheliograph I now use for photographing the prominences, though a single concave mirror is employed instead of two objectives in the collimator and observing telescope. The apparatus will be tried in Colorado or Arizona during the coming spring or summer, as the low Sun and whiteness of the sky make experiments in Chicago useless, at least during the winter months.†

An apparatus in all respects like that of M. Deslandres was devised some years ago by Professor Wm. Harkness for the purpose

* Dr. Huggins has kindly presented me with one of his photographs on which the image appears remarkably like the corona.

† For previous references to this method of photographing the corona without an eclipse see ASTRONOMY AND ASTRO-PHYSICS, November, 1892, p. 792; January, 1893, p. 95; *Photo-Beacon*, February 1893.

of observing the corona without an eclipse,* but it has never been given a practical test.

KENWOOD OBSERVATORY, University of Chicago,
Feb. 15, 1892.

DISTRIBUTION IN LATITUDE OF SOLAR PHENOMENA OBSERVED DURING THE THIRD QUARTER OF 1892.†

P. TACCHINI.

The following results were determined for each zone of 10°, in both hemispheres of the Sun:

Latitude.	Prominences.		Faculæ.		Spots.		Eruptions.	
90° + 80°								
80 + 70	0.007							
70 + 60	0.114							
60 + 50	0.044							
50 + 40	0.048	0.467	0.004					
40 + 30	0.063		0.020					
30 + 20	0.083		0.097	0.502	0.078			
20 + 10	0.066		0.215		0.233	0.455	0.445	0.667
10 . 0	0.042		0.166		0.144		0.222	
0 − 10	0.067		0.081		0.045		0.000	
10 − 20	0.055		0.146		0.256		0.000	
20 − 30	0.101		0.170		0.222	0.545	0.222	0.333
30 − 40	0.109		0.089	0.498	0.022		0.111	
40 − 50	0.067	0.533	0.008					
50 − 60	0.117		0.004					
60 − 70	0.015							
70 − 80	0.001							
80 − 90	0.001							

The eruptions occur nearest the solar equator, while all the other phenomena are always found in higher latitudes. As in the preceding quarter the faculæ, spots and eruptions have their maximum frequency at the same distance north and south of the equator, while the prominences have their maximum at a greater distance, in zones where there are neither spots nor metallic eruptions. It should also be remarked that in the equatorial zone (+ 20° − 20°), where the maxima of faculæ, spots and eruptions occur, the prominences show a relatively small frequency; this would lead one to consider a great number of prominences as the product of conditions very different from those which give rise to spots in the photosphere, while prominences form in the atmosphere of the Sun, and at a very great distance from the limb. This was the case in the prominence which I observed on April 1,

* *Bulletin Philosoph. Soc., Washington,* vol. 3, p. 116-119; *Beiblætter,* vol. 5, p. 128.

† Communicated by the author.

1892, at a distance of 264″.1 from the limb, which afterwards rose 100″ higher, thus attaining an elevation of more than 6 minutes, with no corresponding change at the surface of the Sun.

ROME, Italy, January 3, 1893.

SOLAR STATISTICS IN 1892.*

R. WOLF.

From the solar observations made at the federal Observatory at Zurich and the magnetic observations made at the Milan Observatory, I have deduced for last year, employing the method established by me some years ago, the following values for the monthly means of the relative numbers (r), the variations in declination (v), and the increments (Δr and Δv) which these quantities have received since the corresponding epochs of 1891:

1892.	Zurich. r	Zurich. Δr	Milan. v ′	Milan. Δv ′
January	72.4	55.3	4.33	0.62
February	72.4	49.0	6.27	1.76
March	52.5	42.5	10.31	2.46
April	69.6	50.2	11.89	1.31
May	79.2	36.0	11.47	0.77
June	76.6	27.9	11.66	1.30
July	77.9	18.8	11.76	0.78
August	102.6	70.0	11.55	1.59
September	62.2	10.3	9.06	1.41
October	74.8	24.4	9.10	0.61
November	67.1	26.1	5.56	0.78
December	77.8	47.2	3.07	0.22
	73.8	38.2	8 91	1.13

It follows from this table that the relative numbers and the magnetic variations have both continued to increase considerably, and that the parallelism between these two series, so different in appearance, persists in a quite remarkable manner. This assertion will not be considered greatly exaggerated if it is considered, for example, that the formula,

$$v = 5'.62 + 0.045\, r,$$

which I formerly deduced for Milan, gives for last year

$$v = 5'.62 + 0.045 \times 73.8 = 8'.94,$$

i. e., a value which differs only $\frac{3}{100}$ from the result of observation.

* *Comptes rendus* 30 Janvier, 1893.

SOLAR ELECTRO-MAGNETIC INDUCTION.*

M. A. VEEDER.

In order to determine what it is upon the Sun in any given case that produces an aurora, detailed study of magnetic phenomena is requisite. For the present purpose the pivotal facts respecting such phenomena are their periodicity corresponding to the synodic rotation period of the Sun, their brevity of duration, and abruptness and violence of beginning, and gradual subsequent decline. In conformity with these facts the centres of electro-magnetic activity in the Sun must occupy definite areas, and their inductive effects must be conveyed in accordance with a very sharply defined arrangement of the lines of force in a particular direction chiefly. It is evident also that the Earth must come into range with these lines suddenly, the beginnings of magnetic storms being abrupt and strong and, whenever they occur in the usual series, at the exact interval from each other of the rotation period of the Sun. The endings of such storms on the contrary are gradual and non-periodic, the Earth requiring three or four days commonly to pass out of range. It would seem that this manner of beginning and ending could not co-exist with the location of the originating solar disturbance elsewhere than at the eastern limb. If at the meridian especially the beginnings and endings ought to correspond with each other and to be equally ill-defined and non-periodic, which is not the case.

The period of auroral recurrence has been found to be twenty-seven days, six hours and forty minutes, corresponding accurately to the time of a synodic revolution of the Sun as determined from the average rate of rotation of spots. This period may be termed the solar magnetic month, and it will be of service to construct a calendar based upon it. For this purpose any date whatever may be selected as the starting point from which to begin the enumeration of these solar magnetic months. In order to provide for the fractional parts of a day, each fourth period requires to be lengthened one day so as to comprise the six hours, and likewise each thirty-sixth period so as to comprise the forty minutes. It is evident that on corresponding days of these periods the Sun will always return to the same position in longitude relative to the Earth. Thus this system of dating enables comparison to be made readily as to the facts attendant upon such returns of the Sun to particular positions. The more ex-

* Communicated by the author.

tensively this method of recording the phenomena in question is employed the clearer does it become that there can be no error in the length of the period adopted of sufficient extent to obscure the leading facts and relations. The writer has a diary covering many years dated in accordance with this plan, and likewise extensive tables of auroras and magnetic storms based upon it. It has thus been found that it is most important to record under the appropriate dates the distribution of sunspots and faculæ, the prevalence of auroras, magnetic storms and thunderstorms, and any evidence of sudden and widespread intensification of storms, and likewise the movements in latitude and longitude of anti-cyclones, these being the features which give evidence of being related to solar magnetic induction.

By means of such a record the periodicity of the aurora at the interval named is most finely shown. At times also the substitution and intermingling of thunderstorms on auroral dates becomes a notable feature. Especially important also is the evidence thus obtained that portions of the Sun much frequented by spots are invariably at the eastern limb whenever auroras are in progress. On the other hand, however, the presence at the eastern limb of such a disturbed portion of the Sun does not always insure the appearance of the aurora. Proximity to the plane of the Earth's orbit as well as to the eastern limb appears to be requisite for the production of the aurora and when this is lacking increase of thunderstorms occur instead. Whenever the solar conditions are favorable for the exercise of inductive effects in the manner which has been indicated, intensification of storms follows, and there is a general eastward movement of anti-cyclones. These atmospheric effects are most pronounced near the equinoxes, at which seasons also auroras are brightest and most frequent. In years of great auroral frequency the spots on the Sun and likewise anti-cyclones on the Earth are more persistent than usual in high latitudes.

Thus far the enumeration has been confined as far as possible to the simple facts of observation most prominently displayed in the records. There are in addition certain obvious inferences in regard to the constitution of the Sun and its modes of activity which demand consideration. The fact that the electro-magnetic centers upon the Sun, unlike the spots, remain stationary for extended periods is strong evidence of the existence of a solid nucleus in which they are located. Their mode of action is essentially volcanic, and consequently fitful and irregular. This is the chief element of uncertainty in the entire subject, and is the ex-

planation of many features otherwise anomalous. If, for example, an eruption occurs at the proper instant in the rotation period so that its entire inductive effect is expended along lines of force which embrace the Earth, a tremendous impulse may be experienced from a relatively small outbreak. In like manner a greatly disturbed portion of the Sun may happen to be temporarily quiet at the critical hour and so produce small effect. The sources of these fitful variations are hidden from view in the depths of the Sun, and consequently must remain perplexing. The times and places of their activity may perhaps be determined but not the extent for even so long a period as a single hour in advance. It is plain from the various considerations that have been advanced that the Sun does not produce magnetic storms in virtue of its being a magnet as a whole. On the contrary it is the turmoil of eruption at particular points which originates a state of electrification in the overlying cooler portions of the Sun's surroundings. The motion of rotation carrying forward these electrified areas developes currents in the vicinage dynamically. Under the physical conditions existing in interplanetary space, cosmical dust and *debris* there sufficiently abundant to shine by reflected sunlight as the zodiacal column, furnishes a conducting medium well fitted to convey by induction these solar electro-magnetic impulses to vast distances.

The purposes of the present very brief summary is to emphasize the fact that electro-magnetic periodicities afford a secure basis for extended research in the department of solar physics. The tables and diaries to which reference has been made and which contain detailed proofs of the points here outlined are very voluminous and are not in a fit condition for publication. They constitute the crude material which is in process of being worked up. Specimen extracts from some of them are in print, however, and copies of these will be furnished freely as long as the supply lasts to any who may be sufficiently interested to apply for them.

LYONS, N. Y., Feb. 7th, 1893.

ECLIPSE PHOTOGRAPHY.*

A. TAYLOR.

Photographing the corona during an eclipse of the Sun is not such a simple operation as one might at first imagine. We may recognize in the corona at least four main portions differing in intensity of light—the chromosphere and prominences; the brilliant inner corona with the polar rays; the middle corona, which we may take as extending from 10′ to 30′ from the limb; and the faint extensions which have been traced visually for several degrees from the limb, and which are only very slightly brighter than the surrounding sky.

It is obviously impossible to photograph all these in a satisfactory manner with one exposure. Different exposures must be given to get the different portions of the corona, and a uniform scale on the margins of the plates will enable the relative intensities of the photographic effect to be measured.

M. de la Baume Pluvinel, in a very interesting and valuable paper in Vol 6, No. 9, of the records of the Société Astronomique de France, gives a useful discussion of this question:—"The intensity of photographic action is equal to the product of three factors: the effectiveness of the object-glass, the duration of exposure, and the sensitiveness of the plate. If we indicate the useful diameter of the object-glass by a and the focus by f, the effectivenes defined by the International Congress of Photography is $100\frac{a^2}{f^2}$. On the other hand, if we take plates of gelatino-bromide of silver of normal sensitiveness as our unit, and let t be the length of exposure in seconds, we shall have the following formula to express the photographic action:

$$100\frac{a^2}{f^2}t.$$

"Working with plates of wet collodion, this expression must be multiplied by $\frac{1}{30}$, and with plates of dry collodion by $\frac{1}{300}$. The first photographs of the corona taken with wet collodion from 1868 to 1878 were obtained with a photographic action not greater than 2. Later, thanks to rapid processes, we could obtain plates much more impressed. Thus, in 1883, a photograph obtained by M. Janssen had received a photographic action equal to 918. On the negative thus obtained the corona extended to

* From *The Observatory*, February, 1893.

between 30′ and 40′ from the limb of the Moon, but details of the parts near the Sun were completely wanting. We might ask whether by still further increasing the photographic action we should also extend the limits of the phenomena. Certainly not! for if the photographic action is too intense the faint contrast between the extreme parts of the corona and the sky, which is always more or less illuminated, is no longer appreciable on the negative. We know, indeed, that if we wish to produce a maximum contrast between two half-tones we must only use just enough light for the faintest of the half-tones to give a perceptible image. In America, Mr. Burnham has been engaged in determining the maximum length of exposure to give plates to obtain the best representation of the corona, and has made experiments on the subject by photographing the Moon and white clouds on a faintly illuminated sky."

We can scarcely accept this latter as a correct description of Mr. Burnham's experiments. He photographed the Moon in full daylight, and photographed brightly illuminated clouds round the Sun; the conditions in these cases being totally different from those of an eclipse. His experiments prove, what has never been disputed, that to get slight contrasts with great intensity of light, a long exposure is useless; but the problem with the faint extensions of the corona is to get slight contrast with faint light. My own experiments with the 20-inch mirrors of 45-inch focus at Ealing, when I photographed the Moon surrounded by clouds in faint twilight, were more comparable with the eclipse conditions; and I found that increase of exposure up to a minute gave greater extension, a result which the Eclipse Committee of the Royal Astronomical Society believed would be obtained by the long exposures with mirrors in eclipse work. One second exposure with the 20-inch mirrors will give a photographic action of 19.75 according to the formula, and 60 seconds exposure gives an action of 1185, but these results must be reduced, probably by 10 per cent, owing to loss of light by reflection.

M. de la Baume Pluvinel continues:—"At Salut Isles in 1889 I used five arrangements giving photographic actions varying from 185 to 13. However, doubtless on account of the peculiarly intense illumination of the atmosphere due to the short duration of totality and a great abundance of water-vapor, the negative corresponding to a photographic action of 30 was most satisfactory. But it is very probable that an equally good result might have been obtained with much less photographic action. Thus, Mr. Barnard, to whom we owe the best photograph

of the eclipse of January 1, 1889, worked with a photographic action equal to 0.58."

It would be interesting to know why, if this is the case, the photographic action 30 was better than 13 with M. de la Baume Pluvinel, and why instantaneous pictures of the corona do not show greater extension than any others. At Salut Isles, Mr. Rooney exposed plates to photographic actions of 1.11, 2.22, 4.44, 44.44, 88.88, and 177.77, and his negatives show an increase of extension of the corona with every increase of photographic action. Father Perry, with the 20-inch mirror, obtained plates with photographic actions of 19.75, 98.75, 197.5, 395.0 and 790.0, always obtaining greater extension with greater photographic action. His photograph of 197.5 is not quite equal to Mr. Rooney's 177.76 plate, but the other two plates of Father Perry's series with greater photographic action show still greater extension. Comparisons of Mr. Rooney's photographs and those obtained by Father Perry, by the use of the formula given by M. Pluvinel, strengthen the opinion that the mirror was very probably dewed, but they clearly indicate that so far all the evidence is decidedly in favor of the idea that the greater photographic action gives the greater extension of the external parts of the corona.

Captain Abney finds that we may look upon a photograph as a drawing in which 200 different shades are used, or in other words, that on a correctly exposed negative differences of ½ per cent. in the intensity of light can be detected. It should therefore be possible by correct exposure to detect the corona on the sky when the skylight forms 99½ per cent. of the light and the corona ½ per cent. The correct exposure to detect this slight shade with faint light is totally different from that necessary to detect it with intense light. A certain absolute amount of light is necessary to begin *any* chemical change in a sensitive film, and in photographing extensions of the corona this limit must be reached and can only be reached by long exposure. In Mr. Burnham's experiments on photographing clouds round the Sun, the difficulty was not to get enough light *to start* photographic action, but to *cut down* the light so as to detect ½ per cent. of the total amount. Hence his experiments do not in any way bear upon the question of photographing the extensions of the corona.

The whole process of photographing the faint extensions of the corona is more fairly comparable with that of photographing nebulæ on a moonlight night, and it can scarcely be questioned that a long exposure and great photographic action in this latter case give the best results.

The most enthusiastic advocate of short exposure and small photographic action in the case of the corona would scarcely prefer 3 minutes to 60 minutes when photographing nebulæ on a moonlight night; and as the conditions are fairly comparable, it is difficult to understand why 3 seconds and small photographic action should be suggested for the corona extensions instead of 60 seconds and great photographic action. Of course short exposures are necessary to obtain the internal portions of the corona, but for the faint outlying portions only long exposures can reasonably be expected to give satisfactory results.

ASTRO-PHYSICAL NOTES.

All articles and correspondence relating to spectroscopy and other subjects properly included in ASTRO-PHYSICS, should be addressed to George E. Hale, Kenwood Observatory of the University of Chicago, Chicago, U. S. A. Authors of papers are requested to refer to last page for information in regard to illustrations, reprint copies, etc.

Nova Aurigæ.—A photograph of the region of Nova Aurigæ was taken on the 3d of October, 1892, with the 20-inch reflector, and exposure of 110 minutes, upon which the Nova appears as a star, as well defined as any of the other stars, which are very numerous, on the plate.

There is no trace of nebulosity surrounding the Nova, or in its vicinity, and there is no feature about it suggestive that it is different from other stars.

The diameter of its photo-image measures 21 seconds of arc, and about 85 seconds distant from it, on the n. f. side, is a star, the photo-image of which measures 23 seconds of arc; the Nova is therefore 2 seconds in diameter less than the star.

On the 25th of December 1892 another photograph was taken of the same region, with an exposure of 20 minutes, upon which the Nova has a photo-image of 13 seconds of arc in diameter, and the star referred to has a diameter of 16 seconds. If we proportion the measured diameters, obtained on the days stated, we shall have the following:

$$23'' : 16'' :: 21'' : 14.63 \text{ — the diameter of the Nova.}$$

But the diameter of the Nova measures only 13 seconds, which shows a decrease of $1''.63$ in diameter, between 3d of October and 25th of December.

There is no indication of nebulosity round the Nova, or in its vicinity, on the December plate, and it appears as sharply defined as the other stars.

So far, therefore, as the evidence obtained by the twelve photographs which I have taken between the date of the appearance of the Nova and the 25th of December, there is nothing upon them indicative of a disturbance, such as we might expect to see recorded, if a body of the magnitude and velocity of the Nova had rushed into a nebula, or into a swarm of meteors. On the other side, it might be argued that the great velocity of the star would carry it through, without causing such great disturbance at right angles to the line of flight, according to dynamic law, that a projectile at a high velocity will penetrate through a plate of ron, or of glass, without fracturing them in the manner that a projectile would

at a low velocity. On this hypothesis the inrush of the nebulous or meteoric matter, to fill the vacuum created by the star, might account for the spectra which were observed. ISAAC ROBERTS.

In a letter accompanying the above note Dr. Roberts adds:

"On my photographs I can distinguish between true nebulosity and atmospheric glare around a bright star, say, such as the stars in the Pleiades, which cannot be done by eye observation even by aid of the largest telescopes yet made, and 3″ arc is a measurable quantity on my negatives."

English Eclipse Parties.—In a letter dated Jan. 23, Mr. A. Taylor writes as follows:

"Two expeditions will be sent to observe. The African one will go to Fundium up the Salum River in Senegal. Four observers will go from Liverpool about March 18, and will be met at Bathurst by a British gunboat which will assist during the eclipse work. They will probably arrive at Fundium on April 2.

"The program for the African station will include photometric measures of the visual intensity of the corona similar to those made in Granada in 1886. Professor T. E. Thorpe and Mr. Gray will have charge of this portion of the work. Mr. A. Fowler will photograph the spectrum of the corona with a six-inch objective-prism spectroscope. Mr. J. Kearney will photograph the corona with one of the 4-inch lenses used in previous eclipses and a new Dallmeyer combination which, with a focal length of 5 feet 6 inches, will give a diameter to the moon of 1½ inches. Probably a 20-inch mirror will also go to Africa."

"At Para Curu near Ceara in Brazil, I hope to photograph the corona with a 4-inch lens and a Dallmeyer lens, and to photograph its spectrum with radial and tangential slits. I will let you have details of arrangements later. Mr. Shackleton will photograph the spectrum of the corona with a 3-inch objective prism spectroscope. The climatic conditions being unfavorable, we shall not take a 20-inch mirror to Para Curu."

Two American parties—one under Mr. Bailey of Harvard Observatory and the other under Professor Schaeberle of Lick Observatory—have already sailed for South America to observe the eclipse. A French party is now *en route* to Africa.

The Potsdam Measures of Motions of Stars in the Line of Sight.—An important feature of the volume in which Professor Vogel has published the result obtained with the Potsdam spectrograph has as yet, we think, scarcely received the attention which it merits. Next to the table of numerical results for the various stars observed, (to obtain which was, of course, the object of the whole investigation), the chief value of the book is in the vast amount of information which it contains, with regard to the details of the instruments and processes employed. The investigations recently completed at Potsdam involve no theoretical difficulties, so far, at least, as the main line of the research is concerned, as any uncertainty in the general application of Doppler's principle could not give rise to errors which need be considered in dealing with such moderate velocities as are met with in the stars. The difficulties are those of ways and means,—of instruments and methods of measurement. In many investigations well known methods are followed, and only sufficient reference to them is necessary to show that the customary precautions have not been neglected; but the application of photography to the measurement of the displacement of lines in stellar spectra was a new departure in spectroscopy, involving an immense amount of preliminary ex-

periment, and a detailed description of all the processes is of the greatest value. Professor Vogel's book is a mine of information concerning dimensions of apparatus, instrumental errors, exposures, plates, etc., etc. The data which he has collected must be consulted by all who may seek to extend the work which he has begun, and the Potsdam spectrograph will serve as the standard by which the practical efficiency of future instruments will be measured.

Professor Vogel's results show that visual observations of stellar motions with small telescopes are now little better than a waste of time. A comparison of the Potsdam and the Greenwich measurements, made with telescopes of nearly the same aperture, shows very clearly the superiority of the photographic method, and all the more clearly because the skill of the Greenwich observer is unquestioned. To anyone who has ever tried to fix the exact center of a tremulous almost invisible line in a faint star spectrum,—an operation trying alike to eyes and nerves,—the cause of this superiority will be sufficiently evident. Prolonged exposure makes up for deficiency of light when photography is applied, and the length of the exposure may be increased until the effect of changes in the apparatus begins to show in the photographed spectra.

With very large apertures, visual observations will still be of value, particularly when the character of the spectra under examination is such that photographic processes cannot be advantageously applied. The results obtained by visual observations with the Lick telescope of thirty-six inches aperture are of the same order of accuracy as the Potsdam measures, as determined by comparing the results obtained for bright stars like Aldebaran and Arcturus; but for stars of the Sirian type, with broad diffuse lines, as well as for fainter stars, the advantage would lie with the Potsdam apparatus. Good results should evidently be obtained by applying photography to this class of work with large instruments, and although some difficulties are met with in doing this, the next important advance in the field opened by the Potsdam investigations will, no doubt, be the extension of the measures to stars below the third magnitude, by adapting the photographic method to telescopes of large aperture.

Spectrum of Holmes' Comet.—A favorable opportunity for an examination of the spectrum of Holmes' comet, after the reported anomalous brightening on Jan. 16, did not occur at this Observatory until Jan. 29. The comet was then easily visible in the three-inch finder. With a low power on the 13-inch equatorial, it appeared as a round nebulous patch, brightening toward the center, where there was a small, ill-defined nucleus. With a single light flint prism on the large spectroscope (1.12 inches effective aperture), the spectrum was continuous, with a brighter streak running through it at the position of the nucleus. The bright moonlight caused the sky spectrum to be fairly bright, and the spectrum of the comet seemed to differ from the sky spectrum only in its greater intensity. On closing the slit to dim the sky spectrum, leaving it wide enough, however, to include the brightest central part of the comet, I thought at times that there was a brightening in the continuous spectrum at the position of the green carbon band, but could not be at all certain of its reality. It was, at any rate, perfectly evident that almost the whole light of the comet was represented in the continuous spectrum, which appeared to differ in no way from the spectrum which I observed on Nov. 16 and described in the December number of ASTRONOMY AND ASTRO-PHYSICS. Several attempts have been made to photograph the spectrum with low dispersion, but on no occasion has the sky remained clear for a sufficient length of time.

The hypothesis that this comet has been produced by a collision between two asteroids finds little support in the character of its spectrum. Instead of the bright line or banded spectrum which would result from the supposed collision, we have a continuous spectrum (possibly with traces of the usual carbon bands) which seems to be almost entirely due to reflected sunlight. The brightening observed on Jan. 16 was in all probability caused merely by an increase in the number of reflecting particles in the space surrounding the comet; that is, by an increase of density, which might result from a contraction following the previously observed expansion of the comet, or (which is more in accordance with the observations) from fresh emanations from the nucleus. In any case, the phenomenon is a remarkable one, and it is to be hoped that spectroscopic observations were somewhere obtained on or about Jan. 17, when the nucleus was brightest, and perhaps had a characteristic spectrum. J. E. KEELER.

Spectroscopic Method of Determining the Distances of Binary Stars.—Dr. Rambaut, in replying to a correspondent of *Nature* who suggests the above method points out that the idea is by no means new. Dr. Rambaut himself developed the method quite completely in the *Monthly Notices* for March, 1890, and gave a table of the velocities in the line of sight which might be expected in a number of well-known binaries. He is disappointed that astronomers engaged in spectroscopic determinations of stellar velocities have not paid more attention to this interesting subject. The difficulty is, of course, that the velocities to be expected in the case of a binary whose components can be optically separated are quite small and barely within reach of present methods.

Results of Stellar Spectrum Photography at South Kensington.—On December 8, Professor Lockyer communicated to the Royal Society the results obtained at South Kensington with a six-inch telescope, which has been used for the last two years in photographing the spectra of the brighter stars. Object-glass prisms with refracting angles of $7\frac{1}{2}^\circ$ and 45° respectively were employed at different times to give the requisite dispersion.

The photographed spectra were tabulated with reference to the amount of continuous absorption in the violet, and all the 443 photographs are discussed from the standpoint of the meteoritic hypothesis. An abstract of the paper is given in *Nature*, Jan. 12, in which the spectra to be expected from a consideration of the meteoritic hypothesis, and the actual spectra as obtained by photography, are exhibited in parallel columns. The classification provides for both ascending and descending temperatures, the star α Andromedæ being selected as typical of the hottest stars.

Professor Lockyer considers that these photographs confirm the views which he has held until now as the result of visual observations. We must point out, however, that Professor Lockyer's identifications of stellar and terrestrial spectra are sometimes far from being well established; in some cases the identity can no longer be regarded as even probable.

CURRENT CELESTIAL PHENOMENA.

PLANET NOTES FOR APRIL.

H. C. WILSON.

Mercury, having passed inferior conjunction on March 31, will be morning planet during April. He will reach greatest elongation, west from the Sun, 26° 56′, Apr. 28, but will probably not be visible to the naked eye.

Venus is approaching superior conjunction and will be too nearly in line with the Sun to be observed during April.

Mars will be visible in the west during the early evening. His course during April will be eastward through Taurus passing just north of the group of the Hyades.

Jupiter will be behind the Sun during April.

Saturn, having just passed opposition, is in its best position for observation for this year. The planet is just a little east of the star γ Virginis (see chart in Jan. No., p. 80) and moving westward. Saturn will be in conjunction with the Moon, 50′ north, April 27 at 11^h 30^m P. M. central time. The rings of Saturn will make an angle of about 7° with the line of sight during this month, so that they may be well seen.

Uranus also will be in good position for observation during April. He is about ⅓ of the way on a direct line from the bright star α Libræ to the faint naked-eye star λ Virginis (see chart p. 80). A telescope of moderate power will reveal the light green disc of the planet.

Neptune is past his best position for observation but may be seen in the early evening. He is moving slowly eastward about half way between the two third magnitude stars ε and τ Tauri (see chart in Dec. No. 1892 of this journal, p, 937). On the evening of April 12 Neptune will be 2° 35′ almost due south of Mars.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
			MERCURY.		
Apr. 5......	0 26.3	+ 4 44	5 07 A. M.	11 29.4 A. M.	5 50 P. M.
15......	0 18.0	+ 1 00	4 36 "	10 41.8 "	4 48 "
25......	0 34.6	+ 1 06	4 16 "	10 23.0 "	4 30 "
			VENUS.		
Apr. 5......	0 36.1	+ 2 22	5 27 A. M.	11 39.0 A. M.	5 51 P. M.
15......	1 21.7	+ 7 17	5 14 "	11 45.2 "	6 16 "
25......	2 08.3	+11 55	5 02 "	11 52.3 "	6 42 "
			MARS.		
Apr. 5......	4 12.7	+ 22 12	7 38 A. M.	3 15.0 P. M.	10 52 P. M.
15......	4 40.5	+ 23 16	7 21 "	3 03.5 "	10 46 "
25......	5 08.6	+ 24 02	7 04 "	2 52.2 "	10 39 "
			JUPITER.		
Apr. 5......	2 03.1	+11 28	6 18 A. M.	1 06.5 P. M.	7 55 P. M.
15......	2 12.1	+12 17	5 44 "	0 36.2 "	7 28 "
25......	2 21.4	+13 05	5 11 "	0 06.1 "	7 01 "
			SATURN.		
Apr. 5......	12 36.9	− 1 02	5 39 P. M.	11 37.9 A. M.	5 36 A. M.
15......	12 34.2	− 0 45	4 56 "	10 55.9 "	4 55 "
25......	12 31.7	− 0 30	4 14 "	10 14.1 "	4 15 "

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
			URANUS.		
Apr. 5	14 29.5	− 14 16	8 26 P. M.	1 30.2 A. M.	6 35 A. M.
15	14 28.0	− 14 08	7 44 "	12 49.3 "	5 54 "
25	14 26.3	− 14 00	7 03 "	12 08.4 "	5 14 "
			NEPTUNE.		
Apr. 5	4 30.7	+ 20 20	8 06 A. M.	3 34.1 P. M.	11 02 P. M.
15	4 31.8	+ 20 23	7 26 "	2 54.7 "	10 23 "
25	4 33.1	+ 20 26	6 49 "	2 17.8 "	9 46 "
			THE SUN.		
Apr. 5	0 59.6	+ 6 22	5 34 A. M.	12 02.6 P. M.	6 31 P. M.
15	1 36.3	+ 10 02	5 16 "	11 59.9 "	6 43 "
25	2 13.7	+ 13 26	5 00 "	11 57.8 "	6 56 "

Phases and Aspects of the Moon.

		d	h m
Full Moon	Apr.	1	1 18 A. M.
Apogee	"	5	12 30 P. M.
Last Quarter	"	9	5 35 A. M.
New Moon	"	16	8 34 "
Perigee	"	17	3 54 P. M.
First Quarter	"	22	11 26 "
Full Moon	"	30	5 23 "

Minima of Variable Sars of the Algol Type.

U CEPHEI.

R. A. $0^h 52^m 32^s$
Decl. $+81° 17'$
Period $2d\ 11^h 50^m$

1893.		
Apr.	3	7 A. M.
	5	7 P. M.
	8	7 A. M.
	10	7 P. M.
	13	7 A. M.
	15	7 P. M.
	18	6 A. M.
	20	6 P. M.
	23	6 A. M.
	25	6 P. M.
	28	6 A. M.
	30	6 P. M.

S. CANCRI.

R. A. $8^h 37^m 39^s$
Decl. $+ 19° 26'$
Period $9d\ 11^h 38^m$

Apr.	18	2 A. M.

S ANTLIÆ.

R. A. $9^h 27^m 30^s$
Decl. $—28° 09'$
Period $7^h 47^m$

Apr.	1	8 P. M.
	2	7 "
	3	7 "
	4	6 "
	6	midn.
	7	midn.
	8	11 P. M.

S ANTLIÆ CONT.

Apr.	9	10 P. M.
	10	10 P. M.
	11	9 "
	12	8 "
	13	8 "
	14	7 "
	18	midn.
	19	midn.
	20	11 P. M.
	21	10 "
	22	10 "
	23	9 "
	24	8 "
	25	8 "
	26	7 "
	30	midn.

δ LIBRÆ.

R. A. $14^h 55^m 06^s$
Decl. $— 8° 05'$
Period $2d\ 7^h 51^m$

Apr.	7	2 A. M.
	14	1 "
	21	1 "
	27	midn.

U CORONÆ.

R. A. $15^h 13^m 43^s$
Decl. $+ 32° 03'$
Period $3d\ 10^h 51^m$

Apr.	3	5 A. M.
	10	3 "
	16	midn.

U CORONÆ CONT.

Apr.	23	10 P. M.
	30	8 "

U OPHIUCHI.

R. A. $17^h 10^m 56^s$
Decl. $+ 1° 20'$
Period $0d\ 20^h 8^m$

Apr.	2	6 A. M.
	3	2 "
	7	7 "
	8	3 "
	13	4 "
	13	midn.
	18	4 A. M.
	19	1 "
	23	5 "
	24	1 "
	28	6 "
	29	2 "

λ CYGNI.

R. A. $20^h 47^m 40^s$
Decl. $+ 34° 15'$
Period $1d\ 11^h 57^m$

Apr.	5	7 A. M.
	8	7 "
	11	7 "
	14	7 "
	17	7 "
	20	7 "
	23	7 "
	26	7 "
	29	7 "

Occultations Visible at Washington.

Date 1893.		Star's Name.	Magnitude.	IMMERSION Washington M. T.		IMMERSION Angle f'm N pt.	EMERSION Washington M. T.		EMERSION Angle f'm N pt.	Duration	
				h	m	°	h	m	°	h	m
Apr.	1	*h* Virginis	5.8	13	07	178	13	57	257	0	50
	4	B.A.C. 5254	5.8	13	02	213	13	57	251	0	55
	23	B.A.C. 3138	6.3	3	45	159	5	04	295	1	19
	23	B.A.C. 3206	6.3	11	03	72	12	08	290	1	00

New Asteroids.—Five new asteroids were discovered photographically in January. They will be designated by the letters of the alphabet until the end of the year, when probably the consecutive numbering will be given only to those whose orbits have been determined.

1893.	By	Photo. at	Date.	Mag.	First Observations. Gr. M. T.			R. A.			Decl.		
						h	m	h	m	s	°	′	″
A	Charlois	Nice	Jan. 17	9.0	Jan. 18	8	01	8	08	59.3	+ 9	29	12
B	Wolf	Heidelberg	Jan. 12	13.0	Jan. 12	12	15	8	15	31.9	+ 14	51	57
C	Wolf	Heidelberg	Jan. 16	13.0	Jan. 16	12	47	9	14.3		+ 17	44	
D	Charlois	Nice	Jan. 18	12.5	Jan. 20	8	05	8	19	15.4	+ 16	12	29
E	Charlois	Nice	Jan. 20	12.5	Jan. 21	8	20	8	28	03.7	+ 25	01	56

Occultation of Jupiter, Jan. 23, 1893.—I duly observed the occultation of Jupiter which occurred on the night of January 23, 1893. The night was severely cold and clear and definition remarkably good. The dark limb of the Moon, clear, sharp and well defined, touched satellite IV at $8^h\ 49^m\ 35^s$ E. S. T., which appeared to glide on to the dark limb for a short distance and then slowly disappear. I saw it distinctly projected in the dark body of the Moon. Satellites I, II, and III, also occulted, apparently gradually disappeared at the limb without appearing to glide on, or within it, as did IV. The limb of the Moon at 9^h touched the planet and was very steady and well defined as it passed over it. As the limb approached the planet it seemed to become *concave* at and near the point of contact and remained so until contact took place when instantly it assumed its normal shape.

I failed to observe the dark line on the planet along the edge of the Moon, mentioned by some observers though the limb and planet were as steady, distinct, and sharp as an engraving. The emersion I did not observe. The instrument used was my 5-in. Clark refractor, power 110.

I delayed sending this report as it was so near the time for issuing February number that if you cared to insert it, it would be too late. E. S. MARTIN.

Wilmington, N. C., Feb. 9, 1893.

Dr. Otto Tetens has recently sent us his inaugural dissertation presented for the doctor's degree at the University of Kiel. It is an investigation of the rate of the standard clock of the Bothkamp Observatory. From observations during 1890 and 1891 he finds that the rate of the clock can be closely represented during long periods of time by a rate-formula including terms involving the time, temperature and barometric pressure. He gives for July 31, 1891 the formula

$$\text{Daily rate} = +\ 0^s.0931 - 0^s.000209\ (T - 1891\ \text{July}\ 31.5)$$
$$-\ 0^s.0442\ (t - 10^\circ\ C) + 0^s.0153\ (b - 760\ \text{mm}),$$

in which T is the date, t the temperature (centigrade) and b the barometer reading. H. C. W.

COMET NOTES.

No new comets have been discovered this year, up to the date of this writing. All the comets of last year are receding and growing fainter. Swift's comet is still visible in a 16-inch telescope but too faint for accurate observation. Brooks' comet *d* 1892 is too far south for observation in this latitude. Brooks' *g* 1892 will be difficult during March and April because of its nearness to the Sun as well as its faintness. The same will be true of Holmes' comet unless another outburst like that in January should occur. The change in this comet since Jan. 16 has been an almost exact duplication of its behavior in November. It has expanded to about 10′ in diameter through the head, with a tail about 30′ long. It is, however, now a difficult object to observe micrometrically because there is no definite nucleus. The last glimpse of the nucleus which we obtained with the 16-inch was on Feb. 4, when at moments we could see a very small bright point of about the 14th magnitude.

Regarding the outburst of Holmes' comet in January, Professor C. A. Young writes under date Feb. 4, that Mr. Reed observed the comet with the 9-inch telescope and succeeded in getting its spectrum purely continuous. He thinks the *asteroid collision* theory of its origin extremely improbable, but queries whether if the asteroids were formed by a series of "explosions," breaking up first an original planet and afterwards the pieces from it, this might not be an event of that sort—an eruption from an asteroid.

The following note from Professor Stone's assistant at the Leander McCormick Observatory, was received too late for our last issue.

The Outburst of Light in Holmes' Comet.—I observed comet Homes' on Jan. 13, and found the nucleus very faint and nebulosity diffuse extending over an area having a diameter of about 25′. It was much fainter and more hazy than on the 12th. Clouds interfered until the 16th when on directing the telescope to position given by ephemeris there appeared what seemed to be a bright star in a fog. The center was of a reddish yellowish color and the circular fuzz surrounding it about 30″ in diameter. Clouds came up before a micrometric measure could be made. I could not locate the body in any nebula catalogue so concluded that it was a star behind the nebulous envelope of the comet. Its identity was concealed by the fact that comet Holmes' is receding from the Sun and had been growing fainter. Micrometric measurements of the body on the 17th proved it to have the position and motion of comet Holmes. Brightness of the nucleus estimated at 9.5 mag. Snow storm on the 18th forbade observations. On the 19th the comet showed greater condensation and the nucleus was at least half a magnitude brighter than on the 17th. There was a marked change in the comet's color, it being decidedly bluish. Visible in the finders of the telescope and I saw it with the naked eye. On the 20th the nucleus was fully as bright as before, though the comet as a whole was fainter. Circular nebula around the nucleus not quite as large, about 25″ in diameter. The nucleus was as well defined as 9 mag. stars near and appeared like a star in a nebula. Color still bluish, as noted on the 19th. On the 21st the nucleus was larger, diameter about twice as great as before, but there was no diminution in the apparent brightness of the comet notwithstanding the moonlight. I used the 26-inch and a power of 175. E. O. LOVETT.

Leander McCormick Observatory, Jan. 21, 1893.

Holmes' Comet.—The following few notes on the appearance of the remarkable Holmes' Comet were made with a 3-inch telescope, (objective by Brashear, of Jena glass).

Noticing in the press dispatches of January 18th, that new changes had taken place in this comet, the same evening I looked up its position and came across what appeared to be a wide double star of about 7th and 8th magnitudes; on closer inspection the larger star appeared hazy, and on applying a higher power discovered that the object was nebulous and nearly circular, with a brighter condensation towards the center. On the 21st, it had greatly increased in size and with a low power appeared as a beautiful large, bright planetary nebula, brighter towards the center. Owing to unfavorable weather, another observation was not obtained until the evening of February 7th, when the appearance of the comet was entirely changed, it had now become much larger and quite diffuse. On the 10th, it appeared still larger but fainter. On the 12th, it was somewhat fainter and seen best with a low power, with a power of about 60 it was very difficult to observe. It had apparently decreased in size on the 14th, but was too near B Trianguli (which was in the same field of view) to estimate its brightness. On the 18th and 19th, it was apparently diminishing in size, and somewhat oval in appearance, but even with a very low power it was hard to determine the extent of the nebulosity; with a power of about 60 it was an exceedingly difficult object seen only by "oblique vision" as a mere vapor on the dark background of the sky.

Alta, Iowa, Feb. 20th, 1893. DAVID E. HADDEN.

Biela's Comet.—A few words regarding this comet may not be out of place. Persons who expected a collision between the earth and this comet last fall, had not carefully noted the dates of its perihelion passage. The three times of this event of which the dates are before me, are those of November 17 (27), 1832; February 11, 1846; and September 23, 1852. The interval between the last two dates is 6 years, 7 months and 12 days. The preceding interval is just double the time. But Robinson, quoting Littrow, gives November 27, as indicated above, but this may be an error of the types.

In Young's Astronomy you find this: "On November 27, 1872, just as the earth was passing the track of the lost comet, she encountered a wonderful meteoric shower." Now the comet was due at perihelion on the 29th of the preceding July,—and had passed the point of nearest approach to the earth's orbit about ten weeks earlier,—in the middle of May. Wherefore six months after the body of the comet was due at the collision point, there was a "wonderful meteoric shower." There can be but little doubt that these meteors are the pulverized products of its disintegration,"—six months behind the fore-front of the system.

Similarly in 1892, the comet, if an entire body, should have passed the danger point about the middle of last March, and the perihelion about the 5th of June,—8 months afterwards, on the 23rd of November, there was another good display of meteors. It is well known that any disturbance of the orbit by any of the planets, would pull the node westward. And I think it positively shown by the display of the 23rd, not only that the comet is disintegrated, but also that the fragments are scattered along the orbit for about one-fourth of its whole extent, or about 500 million miles. Supposing the comet's period to be as above given, but that the node has retrograded 4 days, then the comet will pass the danger point about two weeks in advance of the earth in November, 1898; but will be two weeks late in 1931; yet if the node should retrograde meanwhile

so that the comet should reach the node two weeks earlier than the regular rate would demand, then the comet and the earth will come into direct collision. Timorus people will have ample time to make way with themselves long before the clash comes; other kinds may turn out and see the grand display. R. W. M.

Ephemeris of Comet 1893 I (Brooks Nov. 19, 1892).

[Continued from page 185].

Gr. Midn.		App. R. A. h	m	s	App. Decl. °	′	log r	log. Δ	Br.
Mar.	5	0	42	38	+21	34.6	0.1737	0.3380	0.56
	6		43	36		21.5			
	7		44	34	21	08.8			
	8		45	31	20	56.4			
	9		46	27		44.4	0.1842	0.3564	0.48
	10		47	22		32.7			
	11		48	17		21.4			
	12		49	11	20	10.4			
	13		50	05	19	59.8	0.1947	0.3732	0.42
	14		50	58		49.4			
	15		51	50		39.3			
	16		52	41		29.5			
	17		53	32		19.9	0.2051	0.3884	0.38
	18		54	22		10.6			
	19		55	12	19	01.5			
	20		56	01	18	52.6			
	21		56	50		44.0	0.2157	0.4022	0.34
	22		57	38		35.6			
	23		58	25		27.4			
	24		59	12		19.4			
	25	0	59	59		11.5	0.2261	0.4146	0.30
	26	1	00	45	18	03.8			
	27		01	31	17	56.4			
	28		02	16		49.1			
	29		03	01		41.9	0.2365	0.4258	0.27
	30		03	45		34.9			
	31		04	29		28.0			
Apr.	1		05	13		21.3			
	2		05	56		14.7	0.2468	0.4358	0.25
Apr.	3		06	39		8.2			
	4		07	21	17	1.8			
	5		08	03	16	55.5			
	6		08	44		49.4	0.2570	0.4448	0.23
	7		09	26		43.4			
	8		10	05		37.4			
	9		10	45		31.5			
	10		11	25		25.7	0.2670	0.4526	0.21
	11		12	04		20.0			
	12		12	43		14.5			
	13		13	22		09.0			
	14	1	14	00	+16	03.6	0.2770	0.4596	0.20

A Remarkable Meteor.—December 9th, 1892, about 9 o'clock P. M., a remarkable and magnificent meteor shot out from the constellation Andromeda and moved slowly and majestically towards the northeastern point of the horizon. When first seen here, it was about the size and color of an orange, but rapidly increased in brilliancy and size until before it disappeared below the horizon it was of the apparent size of the full Moon and was surrounded by a mass of glowing vapor which further increased its size to that of the head of a flour barrel. It soon became intensely brilliant, flashing at times a greenish blue light, throwing off sparks "fast and furiously," and left behind it a dense stream of vapor 30° to 40° in length.

A gentleman who was at Jacksonville, N. C. (about 50 miles N. E. from Wilmington), and saw it, gave me the same description of the meteor in every particular. To-day I learned that the same meteor was observed at Washington, N. C. (about 125 miles N. by E. from this city). The writer says: "We saw the meteor which passed over, going in a northeastwardly direction. It did not seem to be very high and was going at a rapid rate. It was about the size of a man's head with a tail of some length and small pieces were flying off and it was a beautiful sight."

It must have passed to sea about the neighborhood of Norfolk, Va., and probably fell into the ocean. E. S. MARTIN.

NEWS AND NOTES.

This number is sent only to such subscribers as have renewed, or ordered a continuance of their subscriptions for the current year.

The contents of the February number of this journal will be found on page 288. It is repeated for the information of readers who may not have seen that number.

It is particularly requested of all correspondents that articles intended for publication should reach this office on or before the 15th of the month preceding that of publication. News items or paragraph notices should not be later than the 20th, that mailing may regularly come on the last day of the month.

Professor Rowland's List of Standard Wave-Lengths.—We have already in type a table of more than 20 pages of standard wave-lengths of various substances, recently prepared by Professor Rowland of Johns Hopkins University, Baltimore. It is scarcely necessary to add that this contribution to Astronomy will be of world-wide use as a standard of reference.

E. E. Barnard at Goodsell Observatory.—The visit of E. E. Barnard and wife at Goodsell Observatory of Carleton College, on February 21st, was one of the most enjoyable and instructive occasions in the history of the Observatory. During the forenoon of that day, Mr. Barnard spoke to groups of students at the Library of the Observatory almost continuously. He had for exhibition 35 large photographic plates, which were intended as illustrations of some of the lines of his recent work in celestial photography at the Lick Observatory. The themes were different portions of the Galaxy, showing wonderful cloud masses of stars, star groups, and star configurations in great variety. His descriptions of these various features plainly showed his intimate acquaintance with them by the aid of the telescope and the photographic plate. His views of the great telescope, the buildings of the Lick Observatory and adjoining mountain scenery were also greatly enjoyed. In the afternoon Mr. Barnard continued the exhibition of his photographs to increasing numbers of visitors including a goodly number of residents from the city. At four o'clock, without a moment's time for preparation, he kindly accepted the invitation of professors to speak at the College Chapel before the body of students and friends from the city. He was asked to speak on "Jupiter and his Satellites." He talked for an hour, in a clear and very ready manner, giving a résumé of his observations concerning the chief markings of the planet's surface for a period of fourteen years. His modest references to

the discovery of the fifth satellite of this planet was generally noticed and commented on, but the brilliancy of the discovery lost nothing through Mr. Barnard's modesty, which was universally admired, for genius and a noble character could not thus be hidden.

Mr. Barnard went from Northfield to Chicago to visit his old friend, Mr. Burnham and others. From this point he will visit his former home in Nashville, Tennessee. Then, about April 1st he will sail for Europe. His leave of absence from Lick Observatory is for 6 months or more as he may desire. The Board of Regents of the University of California evidently appreciate Mr. Barnard's services, for they have raised his salary, propose to build for him a house on Mt. Hamilton and have given him a generous vacation.

It will interest our readers to notice that Mr. Barnard has become one of the associate editors of this Journal. His work will have prominent place in these pages in the future.

The Peters' Star Catalogue Decision.—It will be remembered that the famous Star Catalogue case, Peters vs. Borst, which was tried four years ago was appealed by the defendant. The decision on this appeal, handed down last fall, is now before me. It is written by Justice Hardin, Justice Merwin concurring. After reviewing the main points of the case and sustaining the rulings of the Court upon the trial, the decision concludes:

"Upon a careful examination of the appeal book we have not found any strong grounds to believe that the merits have not been fully and fairly passed upon by the trial court, and we discover nothing in the case to indicate that a new trial would be more likely to result in a more just conclusion than the one reached at the circuit. Our conclusion is that the decision at the circuit should remain. Judgment affirmed with costs."

J. G. PORTER.

Publications of the Observatory at Berlin.—The sixth volume of the new series of publications of the Observatory at Berlin has recently been received. It contains the account by Professor V. Knorre, of a new method of measurement of double stars with a double-refracting prism micrometer, proposed by Dr. V. Wellmann, together with Dr. M. Brendel and Professor V. Knorre. There are appended observations of double stars, according to the new method, by Professor Knorre, Mr. T. J. J. See and Dr. Wellmann. There are also papers by Dr. Brendel on the retraction of light in prisms of uniaxial crystal and their use for micrometrical measurement, and by Dr. Wellmann on the influence of temperature on the measures made with double refracting prisms.

Publications of the Observatory at Karlsruhe.—The fourth volume of the publications of this Observatory, edited by Dr. W. Valentiner has recently come to hand. It contains the detailed observations and mean results of meridian circle observations of something over one thousand stars in the zone from the equator to -10° declination. There are also papers by Dr. Boy Matthiessen on measures of the star-cluster G. C 1119, and by Dr. Friedrich Ristenpart on the constant of precession and the motion of the solar system. The results obtained in the last paper agree, in general, with the results obtained by other investigators, in putting the apex of the solar way at about R. A. 280° and Decl. $+30^\circ$. The author shows however that quite different results may be obtained by different methods of treating the same data. He finds for the annual translatory velocity of the solar system about 5.41 radii of the earth's orbit.

Micrometrical Measures of Some Double Stars with New Companions, and of Five New Pairs.—(Paper read before The Astronomical and Physical Society of Toronto, 24th January, 1893.) The following new companions have been discovered during a revision of some stars for the new edition of "Celestial Objects." The telescope used is the 17¼-in. reflector; the micrometer was made by Troughton & Sims. The mean measures only are given. The stars are arranged in their order of constellations. The R. A. and Decl. are for 1900. The magnitudes are on Struve's scale. The work was done from September to December, 1892.

No.	Star.	R. A.		Decl.		P.	D.	Mags.	n.	
		h	m	°	′	°	″			
1	Sigma 994	5	52.8	37	14	220.9	9.13	7.2......12.0	1	AC.
2	P III .97	3	34.5	59	39	96.2	18.68	6.0......13.8	1	AB.
						302.4	34.65	......13.0	1	AC.
3	Dembowski	4	32.0	53	17	69.0	18.04	8.5......12.5	3	AC.
4	Beta Camelop	4	54.5	60	18	167.4	14.81	7.0......11.5	2	BC.
5	Cassiop	0	25.6	56	14	113.3	6.36	8.2...... 8.5	3	AB.
6	Anon	0	29.4	56	3	158.5	8.66	8 9	3	Yellow: blue.
7	Anon	0	49.7	57	15	116.3	4.86	9.6...... 9.8	2	AB.
8	Sigma 18 ’	1	49.3	60	48	75.2	29.9	7.0......13.5	2	AC.
9	Sigma 306	2	43.4	60	1	74.3	17.02	7.1......13.8	2	AC.
						112.0	19.21	......13.5	2	AD.
						105.6	27.40	......13.0	2	AE.
10	Anon	23	56.7	59	26	289.3	10.13	8 9	..	Yellow: blue.
11	Webb	19	46.8	44	54	327.9	31.54	8.0...... 9.0	5	AB.
						138.8	7.68	......11.5	3	AC.
12	Anon	20	45.2	32	51	245.6	9.61	8.7...... 9.0	3	AB very red: blue.
						141.1	17.86	......10.0	3	AC.
13	59 Cygni	20	56.6	47	8	224.1	37.09	4.7......13.5	3	AD.
14	H. V. 66	7	21.7	22	21	23.9	11.31	7.0......13.5	1	
15	Sigma 2916	22	27.0	40	42	118.0	16.56	8.0......13.8	3	BD.
16	8 Lacertæ	22	31.4	39	6	200 ±	9.95	8.0......13.8	3	Dd.
17	Sigma 446	3	41.9	52	21	42.7	11.59	7 ......12.5	1	AC.

No. 3. Place of 2 Cameli. No. 9 Dembowski measured a more distant *comes*, there are three others still more distant.

Where the stars are below 12.5, the measures have been made with great difficulty and show considerable differences both in distance and angle. The mirror has not been silvered for four years and so the faint stars are difficult objects with it.

T. E. ESPIN.

Towlaw, Darlington, England, 1892, Jan. 6.

In looking over the foregoing list of distant companions, I have made the following notes:

No. 1. If this is Σ 994, as it appears to be from the declination, the hour of R. A. should be 6 and not 5 as given in the MS. In Struve this is a wide pair (25″) of bright stars, and therefore the distant star measured above should be called C, according to the usual method of lettering companions in the order of their distances from the primary. The bright pair is also H 3286, and Herschel notes, "two small stars near," but this probably has reference to stars still more distant than B.

No. 3. The principal star of Dembowski's pair is O. Arg. N. 5001. He did not see the 18″ star measured by Mr. Espin, but connected a distant, wide triple with A of this pair.

No. 4. South measured a very remote 9m star at a distance of 80″ from the primary, and C is a faint star near that. There has been no sensible change in the relative positions of A and B, and therefore the proper motion may be assumed to be very small.

No. 9. The most distant star, E, was measured by Dembowski in 1867, $P = 156^\circ.9$; $D = 27''.48$. The discrepancy in the position-angle will be noticed.

Evidently there is a clerical error in one or the other. As Dembowski measured it on a single night only, it is probable that Mr. Espin's angle is correct. The other stars C and D have not been measured before. Dembowski called the magnitude of E 11.5.

No. 10. This star is O. Arg. N. 26323. It is noted as "duplex" in that catalogue. Many years ago with the 6-inch I looked up all of the stars having this note attached to them in Argelander. This object was estimated, 290° : 10″ : 9......9.5 (1875). As all of these pairs were very wide or faint, I did not follow them up with the micrometer.

With so large an aperture, assuming that the definition is what would be expected in a much smaller refractor, it seems strange that Mr. Espin should not have picked up some pairs close enough to make physical systems. An aperture of this size should be sufficient for the discovery of pairs down to 0″.3. This, however, would depend entirely upon the definition of the mirror, the light power being of very little importance. S. W. B.

Astronomical Journal Prizes.—By an oversight the following important announcement was omitted from our last number. It is taken from *The Astronomical Journal*, No. 284.

"A gentleman, earnestly interested in the development and progress of astronomy in his native land, has authorized this Journal to offer two prizes, for resident citizens of the United States.

"He expresses the hope that it may be possible to offer similar prizes in subsequent years, although only two are proposed at present, the requisite amount for these having been placed at the editor's disposal.

"They will be known as *Astronomical Journal Prizes*, and will be given either in money, or in the form of a suitable gold medal of the value of two hundred dollars, with the remainder, if any, in money, at the option of the recipient.

"The awards will be made by a commission of three judges, to be selected from American astronomers, and their names to be announced in due time.

"The prizes now offered are for researches tending to advance our knowledge of cometary orbits, and are these.

I.

"For the observer making the best series of determinations of the positions of comets during the year ending the thirty-first of March, 1894, a prize of two hundred dollars. The conditions to be considered in the award will be the accuracy of measurement and reduction, the number of the observations and their judicious distribution along the geocentric paths, and the promptitude of their publication. To equalize the claims of observers, due allowance will be made for the different optical powers of the telescopes used. Also, since there seems to have been a tendency to neglect such comets as are observable only in the morning, regard is to be had in the award, to the especial usefulness of observations made at inconvenient hours.

II.

"For the best discussion of the path of a periodic comet, with due regard to its perturbations, of the kind ordinarily known as the definitive determination of the orbit, a prize of four hundred dollars. The investigation must, however, have been made within the two years next preceding 1894, Sept. 1, and the manuscript (which will be returned to the author) transmitted, not later than that date, to some one of the judges.

"In these awards it will be left to the discretion of the judges to decide

whether in case of uncertainty on account of nearly equal claims of two candidates, either of the prizes ought to be divided. Also, in case that either award should not, in their opinion, be fully justified, they will be authorized to withhold the same; in which event it will be offered again, under the same conditions, for the next ensuing year.

"Should similar prizes be offered in the coming year, it is intended that one of them shall be for the best series of determinations of maxima and minima of variable stars during the years 1893 and 1894."

In *Astronomical Journal* No. 288 we find the following additional announcements:

"The commission of Judges designated for the award of these prizes consists of Messrs. Asaph Hall, Seth C. Chandler and Lewis Boss

"Two additional prizes are hereby offered, for the year 1895, subject to the same conditions as were prescribed for those of the year 1894.

I.

"For the observer making, by Argelander's method, the best series of determinations of maxima and minima of variable stars during the two years ending 1895, March 31, a prize of two hundred dollars. A principal basis for the award is to be the extent to which the determinations will contribute to our better knowledge of the periodic variables, by furnishing the largest number of maxima and minima of the largest number of stars, having especial regard to stars whose characteristics are at present not very well known.

II.

"For the most thorough discussion of the theory of the rotation of the Earth with reference to the recently discovered variations of latitude, a prize of four hundred dollars. The manuscript (which will be returned to the author) is to be transmitted to some one of the judges, not later than 1895, March 31."

These announcements are certainly gratifying to both professional and amateur astronomers. They ought to result in stimulating a great deal of useful effort and without doubt some important results. There is perhaps no lack, in this country, of observers of comets, but it is unfortunately true that many of the observations have much less value than they would have if they were made more carefully and at judiciously chosen times. There is a notable lack, in this country, of mathematical investigators in astronomical lines. The great bulk of the work of definitive determination of orbits of comets and planets has been done in Germany and France. Two or three names only keep up our reputation in connection with the theories of the Moon and Earth. It is therefore to be hoped that there may be many competitors for the prizes II of 1894 and 1895.

The first prize for 1895 is one which should attract especially the attention of amateurs, since the observations require only a good eye, a star-atlas and catalogue of star-magnitudes, and a moderate amount of perseverance. An opera-glass is a useful aid in variable star observations, but it is not necessary, many very valuable results having been obtained with only the apparatus mentioned above. Of course only one can receive the prize, but each observer is liable to be made famous by the discovery of new variable and temporary stars.

Astronomical Clock Correction.—In the *Monthly Notices*, No. 1, Vol. LIII, will be found a paper on the "Probable Error of the Clock Correction, when both the clock rate and the instrumental constants are found by the least squares solution of a single night's observations," by the Rev. John T. Hedrick, S. J., Georgetown College Observatory, District of Columbia. A brief summary at the close of the paper is given, as follows:

The epoch of the clock correction of maximum weight, or minimum probable error, is not, in general, the mean of the times of observation when, besides the constant clock correction and the clock rate, instrumental constants are also determined from observations.

If these quantities are found by a least squares solution, this epoch is before or after the epoch assumed for the constant clock correction, by an interval which is the quotient of the co-efficient of the constant clock correction in the normal equation for the rate by its co-efficient in its own normal equation, after the elimination of the other unknowns.

If we count from this epoch, the probable error of the clock correction at any other time is what it would be if the constant correction and the rate were independently observed quantities—that is, its square is the sum of the square of the probable error at this epoch and the product of the square of the probable error of the rate into the square of the interval from this epoch Hence the square of the probable error of the clock correction, at this epoch, is equal to the square of the probable error of the clock correction, at the assumed epoch, minus the product of the square of the probable error of the rate into the square of the interval between the two epochs.

Chicago Academy of Sciences, Section of Mathematics and Astronomy.—The regular monthly meeting was held on Tuesday, Feb. 7, at the Chicago Athenæum. Professor Hough in the chair. Officers for 1893 were elected as follows:

Chairman, George W. Hough; Recorder, George E. Hale; Executive Committee, S. W. Burnham, E. H. Moore, G. A. Douglass.

Dr. T. J. J. See, of the University of Chicago, presented a paper on the "Evolution of the Double Star Systems," which was illustrated by means of figures and lantern projections. It contained a *resume* of the researches recently published in his *Inaugural Dissertation* at the University of Berlin. The speaker, in presenting the paper, reviewed the successive steps in the progress of Cosmogony made by Laplace, Thompson, and Darwin, and pointed out the importance of the work of each. Laplace's hypothesis of ring-formation, though mathematically sound, was seldom realized in nature, as he inferred from the well known rarity of ring-nebulæ, whilst the great abundance of double nebulæ and double stars would seem to indicate that the general process of division was a sort of gravitational "fission," as is also confirmed by the mathematical researches of Darwin and Poincaré on the figures of equilibrium of rotating masses of fluid.

Dr. See explained how tidal friction could increase the eccentricities of the double star orbits, and showed that the theory advanced in his *Inaugural Dissertation* explained the leading peculiarities of the double star systems, viz.:—

(1). The large eccentricities of the orbits.

(2). The large mass-ratios of the component bodies. Adjourned.

George E. Hale, Recorder.

New York Academy of Sciences: Astronomical Section.—*Minutes of the Meeting, 1893, January 9.*—The Section was called to order at 8:15 P. M., Professor Rees in the chair. A paper was read by Mr. Harold Jacoby on "The parallaxes of μ and η Cassiopeiæ, deduced from Rutherfurd photographic measures. The results obtained are the following:

Parrallax of μ Cassiopeiæ $= + 0''.275 \pm 0''.024$.

Parrallax of η Cassiopeiæ $= + 0''.232 \pm 0''.067$.

The paper will appear in the annals of the Academy.

Professor Rees made a few remarks on the above paper, after which Professor

Geo. E. Hale, of the University of Chicago, described some of his recent investigations in solar physics. Professor Hale showed lantern slides of the apparatus used by him at the Kenwood Observatory, and some very remarkable photographs of prominences and faculæ, which he has obtained in full sunshine. Adjourned.

HAROLD JACOBY,
Secretary Astronomical Section.

New York Academy of Sciences, Astronomical Section.—*Minutes of the Meeting 1893 Feb. 6th.*—The Astronomical Section was called to order at 8:15 P. M., Professor Rees in the chair. The following paper was read: "A Theory of the Formation of Lunar Craters," by G. K. Gilbert. The theory agrees with the meteoric theories of Proctor, Meydenbauer and others in that it ascribes the craters to the impact of bodies colliding with the moon. It differs as to the previous history of the incident bodies. It postulates as the antecedent of the moon an annulus of many small bodies surrounding and revolving about the earth as does the ring of Saturn about the planet. The components of this ring afterward segregated so as to constitute a smaller number of larger bodies, and finally a single body, the moon. The craters of the moon's surface, large and small, are the impact scars of those minor aggregates which were last captured by the moon.

After the moon had acquired approximately its present mass the velocity of impact for bodies of the system was about 7700 feet per second. The energy due to this velocity, if converted into heat, was more than sufficient to fuse the colliding body, assuming that body to have the specific heat and fusing point of diabase. The impacts of small bodies seem to have produced deformation without fusion; but in the impacts of larger bodies more energy was applied to each unit of surface, and parts of projectile and target were fused, producing the level plains of the larger craters. The recoil of the liquefied and softened rock toward the center produced the central hill characteristic of lunar craters. The corrugated rim of the typical lunar crater is due to outward thrust; the inward facing cliff overlooking the inner slope, and the broken terraces below it, are due to land slips, a part of the rim falling back into the fused tract.

The round *maria*, such as *M. Crisium* and *M. Serenitatis*, are regarded as large craters, and the Caucasus-Appenine-Carpathian mountain chain as the remnant of a crater rim with a radius of 400 miles.

Certain parts of the surface are observed to be sculptured by an agency acting along lines which, for each locality, are nearly parallel. Grooves are plowed, crater rims are notched, and ridged additions appear to have been made to the surface. The same districts have been flooded by liquid and viscous matter, diminishing the depth of the larger craters, obliterating the small craters, partly filling cracks (rills), and afterward solidifying. In some low-lying districts the more liquid part of this matter collected, producing plains of the second order of magnitude and even *maria*. The lines of sculpture of these districts radiate from a point in the *Mare Imbrium*. It is believed that the collision of a very large moonlet at this place, under circumstances causing much fusion, hurled a deluge of molten and fragmental rock in all directions, flooding and partially remodeling a fourth part of the visible face of the moon. The central tract of the moon lies within the flooded area, and to this fact is ascribed the often noted contrast between its topography and that of the "honeycomb" district about the south pole.

The paper is to be printed in full in the Bulletin of the Philosophical Society of Washington.

After remarks by Dr. Bolton, Mr. Jacoby, and Professor Rees, the Section adjourned. HAROLD JACOBY, Sec'y Astron. Section.

Camden Astronomical Society.—At the regular meetings of this Society held during the year 1892 the following papers were read,

The Camera in Astronomy, by T. Worcester Worrell.
Tidal Friction, by Herbert Whittaker.
The Theory of the Spectroscope, by E. E. Read, Jr.
Lightning Photography, by W. R. Jennings.
An absolute point for Right Ascensions, by E. F. Moody.
The light of Jupiter, by R. M. Luther, D. D.

Astronomical and Physical Society of Toronto, Ca.—The annual meeting of the Astronomical and Physical Society of Toronto, held in January last, considered various topics of general interest. The following extract from a communication to the society from Professor W. H. Pickering is timely:

"The nomenclature upon Mars is certainly in very bad shape, and I should be glad to join in any movement to improve it. I feel the more interest in the matter as I hope to publish a map of the planet, showing a number of features not previously located. Personally, I find Professor Schiaparelli's names often very long and very hard to remember. The English nomenclature, in that respect, seems to me much superior. On the other hand, if that is retained, it seems to me the same difficulty will arise in the future that now exists in the case of the moon—very inconspicuous and uninteresting peaks commemorate great names like Herschel, Le Verrier, and Encke, while much more important summits are named after mediocre men who lived long before them. Moreover, it seems to me a little presumptuous to foist any man's name upon a grand natural object. I am quite prepared in my work to adopt any plan of nomenclature that meets with general acceptance."

The principal address at this meeting was that given by Dr. Otto Hahn on "Meteorites" in connection with which he exhibited a number of micro-photographs and specimens of meteors. He discussed the chemical and physical nature of the meteorite, and maintained that they are not broken planets, but that most of them floating in space are of the same general shape and constitution, as when found. Dr. Hahn is said to have a large collection of meteorites and that he has given considerable attention to the study of them. He prepared his own slides and showed the details explained by means of several microscopes.

Two other meetings of this society have been reported which show it to be very prosperous financially, and also indicate that it is fully maintaining its standard for good and useful work. As a means of popular instruction in science nothing can take the place of such a society.

BOOK NOTICES.

Cours d'Astronomie a l'usage des etudiants des facultes des sciences par B. Baillaud, director de l'observatoire de Toulouse. Premiere partie, Quelques théories applicable a l'étude des sciences experimental, Paris, 1893.

The author begins with the principles of probabilities and their application to the theory of errors of observation, which are needed at the outset by a student in practical astronomy. He then takes up the study of optical instruments in a very complete manner, giving first the general theories then their special application to the principal astronomical instruments. The last chapters treat of the measurement of angles and arcs, methods of calculation and the problem of interpolation.

The second part, not yet published, is to be devoted to astronomy itself, including the determination of orbits, of planets and comets, the theory of the Moon and the calculation of perturbations.

CONTENTS FOR FEBRUARY.

PUBLISHER'S NOTICES.

The subscription price to ASTRONOMY AND ASTRO-PHYSICS in the United States and Canada is $4.00 per year in advance. For foreign countries it is £1 or 20.50 marks per year, in advance. Recent increase in price to foreign subscribers is due to increase of postage because of enlarged size during the year 1892. Messrs. Wesley & Son, 28 Essex Street, Strand, London, are authorized to receive subscriptions. Payment should be made in postal notes or orders or bank drafts. Personal checks for subscribers in the United States may be used.

Currency should *always* be sent by registered letter.

Foreign post-office orders should *always* be drawn on the post-office in Northfield, Minnesota, U. S. A.

All communications pertaining to Astro-Physics or kindred branches of physics should be sent to George E. Hale, Kenwood Observatory, of the University of Chicago, Chicago, Ill.

For information of correspondents, the names and addresses of the associate editors of ASTRO-PHYSICS are given as follows:—

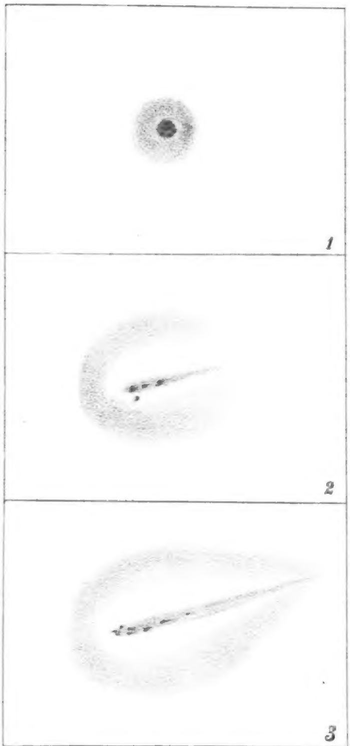
James E. Keeler, Observatory, Allegheny, Pa.; Henry Crew, Northwestern University, Evanston, Ill.; Joseph S. Ames, Johns Hopkins University, Baltimore, Md.

All matter or correspondence relating to General Astronomy, remittances, subscriptions and advertising should be sent to Wm. W. Payne, Publisher and Proprietor of ASTRONOMY AND ASTRO-PHYSICS, Goodsell Observatory of Carleton College, Northfield, Minn.; and the Associate Editors for General Astronomy are: S. W. Burnham, Government Building, Chicago Ill.; E. E. Barnard, Lick Observatory, Mt. Hamilton, Cal., and H. C. Wilson, Goodsell Observatory, Northfield, Minn.

Manuscript for publication should be written on one side of the paper only and *special care should be taken to write proper names and all foreign names plainly*. All drawings for publication should be *smoothly* and *carefully* made, in *India Ink* with lettering well done, because such figures are copied exactly by the process of engraving now used. If drawings are made about double the size intended for the printed page, better effect will be secured in engraving than if the copy is less in size. It is requested that manuscript in French or German be typewritten. If requested by the authors when articles are sent for publication, *twenty-five* reprint copies, in covers, will be furnished free of charge. A greater number of reprints of articles can be had if desired, at reasonable rates.

Rates for advertising and rates to news agents can be had on application to the publisher of this magazine.

PLATE XIX.



HOLMES'S COMET.

1.—1892,	NOV.	9,	5$^{H.}$	50$^{M.}$	G. M. T.
2.—1892,	"	16,	10	45	"
3.—1892,	"	19,	14	15	"

10 INCH REFLECTOR POWERS 60 AND 97.

W. F. DENNING.